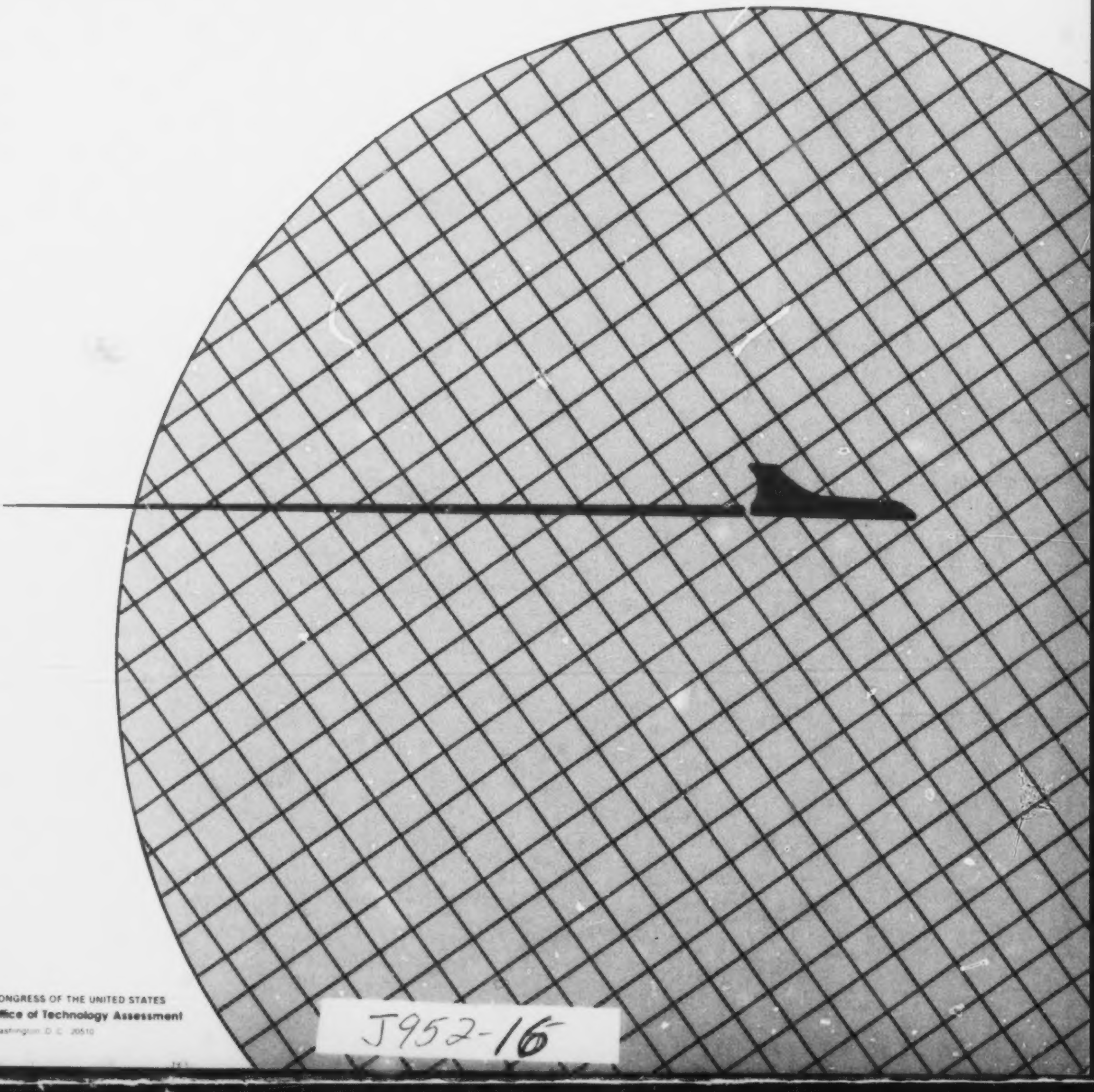
AIRPORT AND AIR TRAFFIC CONTROL SYSTEM



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Foreword

Air transportation is expected to continue growing during the next two decades. In dealing with this growth it will be important to ensure safety and minimize the costs of the system to the Government and airspace users. Large investments are now anticipated in both airports and air traffic control systems, investments that require unusually long leadtimes. For these reasons the House Committee on Appropriations has requested that OTA conduct an assessment of airport capacity and related air traffic control issues.

This subject is, more than most, a moving target. There have been rapid changes in Federal Aviation Administration (FAA) plans in recent years, and these plans have been further complicated by airline deregulation and the aftermath of the Professional Air Traffic Controllers Organization strike. These events affect future plans because they influence the rate of growth and where that growth will occur. There also continue to be rapid and significant changes in the aviation, telecommunications, and data-processing technologies on which the system relies. In addition, these plans are coming before Congress during a period of increasing budgetary constraints.

This assessment is intended to provide a perspective on both airport development aid and FAA's proposed air traffic control system modernization. In both areas there are questions of how much improvement will be needed, how soon it will be needed, and how the funding of improvements will be allocated among airspace users.

John H. Gibbons

JOHN H. GIBBONS
Director

Airport and Air Traffic Control Advisory Panel Members

Raymond L. Bisplinghoff, *Chairman*
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Executive Director
National Association of Noise Control Officials

Secor D. Browne
Secor D. Browne Associates, Inc

Jack Enders
President
The Mitre Corp.

Matthew Finucane
Aviation Consumer Action Project

William T. Hardaker
Assistant Vice President, Air Navigation/Traffic Control
Air Transport Association

William Horn, Jr.
National Business Aircraft Association, Inc.

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Air Line Pilots Association, International

Alton G. Keel, Jr.
Assistant Secretary of the Air Force
Research, Development and Logistics

Clifton A. Moore
General Manager
Department of Airports
City of Los Angeles

Thomas L. Oneto
Planning Officer
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President
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SMS Associates

David S. Stempler
Airline Passengers Association

Richard Taylor
Vice President
Boeing Commercial Airplane Co.

David Thomas
General Aviation Manufacturers Association

Airport and Air Traffic Control System Project Staff

John Andelin, *Assistant Director, OTA*
Science, Information, and Natural Resources Division

William Mills, *Project Director*

Marsha Fenn   M. Karen Gamble   Larry L. Jenney   Paul B. Phelps   Zalman Shavell

Contractors

Adib Kanafani, Institute of Transportation Studies, University of California at Berkeley
Vincent Volpicelli, Port Authority of New York and New Jersey
Jerry D. Ward
Robert Simpson, Flight Transportation Laboratory, Massachusetts Institute of Technology
John Heritage, *Editor*
R. Bryan Harrison

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John Bergling   Kathie Boss   Debra M. Datcher   Joe Henson

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ACRONYMS

AATF	Airport and Airways Trust Fund, trust fund
ACARS	ARINC /Communications Addressing Reporting System
ACAS	Airborne Collision Avoidance System
ADAP	Airport Development Aid Program
AERA	automated en route air traffic control
ANCLUC	airport noise compatability and land use
ARINC	Aeronautical Radio, Inc.
ARTCC	air route traffic control center
ARTS	Automated Radar Terminal System, a computer-driven display system used in terminal areas
ASR	airport surveillance radar
ATA	Air Transport Association
ATARS	Automatic Traffic Advisory and Resolution Service
ATC	air traffic control
ATCRBS	Air Traffic Control Radar Beacon System
BCAS	Beacon Collision Avoidance System
CDTI	cockpit display of traffic information
CFC	central flow control
DABS	Discrete Address Beacon System (Mode S)
DARC	Direct Access Radar Channel
DME	distance measuring equipment
DOD	Department of Defense
DOT	Department of Transportation
DPI	disposable personal income
F&E	facilities and equipment
FAA	Federal Aviation Administration
FAR	Federal Air Regulation
FSS	flight service stations
GA	general aviation
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	inertial navigation system
ITU	International Telecommunication Union
MLS	Microwave Landing System
Mode S	a digital data link system (formerly DABS)
NASCOM	National Airspace Communications System
NAS	National Airspace System
NASP	National Airport System Plan
NOTAMs	Notices to Airmen
O&M	operation and maintenance
OMB	Office of Management and Budget
PANCAP	practical annual capacity of an airport
PATCO	Professional Air Traffic Controllers Organization
PIREP	
PMS	Performance Measuring System
PSR	primary surveillance radar
RCAG	remote communication air-ground
RE&D	research, engineering, and development
ROI	return on investment
RNAV	area navigation
SACDRS	Standard Air Carrier Delay Reporting System
SMSA	Standard Metropolitan Station Area
SSR	secondary surveillance radar
TACAN	Tactical Control and Navigation System
TCA	terminal control area
TCAS	Traffic Alert and Collision Avoidance System
TRACON	terminal radar approach control
TRB	Transportation Research Board
Tri-Modal BCAS	a variation of the Beacon Collision Avoidance System
VFR	Visual Flight Rules
VOR	very high frequency omnirange transmitters
VORTAC	A TACAN colocated with a VOR station

Chapter 1

EXECUTIVE SUMMARY

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Chapter 1

EXECUTIVE SUMMARY

The National Airspace System includes about 6,500 public-use airports connected by a network of air routes defined by navigational aids. Aircraft operating along these routes and in terminal areas near airports are monitored and controlled by a system of ground-based surveillance and communications equipment—the air traffic control (ATC) system—operated by the Federal Aviation Administration (FAA).

In 1980, the 435 airports with FAA towers handled some 180,000 takeoffs and landings per day, or roughly 66 million per year, of which 74 percent are general aviation flights and 4 percent are military. The remaining 22 percent of operations are commercial flights (air carrier, commuter, and air taxi) and are heavily concentrated in a few large airports. The 66 top airports handle 77 percent of commercial operations and 88 percent of passenger enplanements; the 10 largest handle 33 percent of operations and 47 percent of passengers.

This concentration of air traffic at a few large hubs creates congestion and delay, which in turn increases airline operating costs and, ultimately, the cost of air travel for the public. As air traffic and fuel prices increase, the cost of these delays will be magnified. General aviation users of major hubs also feel the effects of delay in the form of access restrictions imposed during peak hours to deal with airport congestion.

Concern about these problems, and about the feasibility and cost of the proposed solutions, prompted the House Committee on Appropriations (Subcommittee on Transportation) to request that OTA undertake an assessment of airport and terminal area capacity and related ATC issues. The Senate Committee on Commerce, Science, and Transportation endorsed the request of the House Committee on Appropriations, which directed OTA to concentrate on four major topics:

- scenarios of future growth in air transportation;
- alternative ways to increase airport and terminal area capacity;
- technological and economic alternatives to the ATC system modifications proposed by FAA; and
- alternatives to the present ATC process.

OTA's major findings are presented below.

AVIATION GROWTH SCENARIOS

FAA expects air traffic to increase considerably over the next 10 to 20 years, and with it the demand for ATC services. Its plans for modernizing and expanding the National Airspace System are predicated on accommodating continued rapid growth. **A key assumption** in FAA's *Aviation Forecasts* has been that there will be **no constraints on future growth** and that new facilities and equipment will be deployed where and when needed to meet demand. **FAA forecasts have consistently exceeded actual demand in the past,** however, with 10-year projections of growth as much as 50 percent higher than actually occurred. This raises questions about the usefulness of FAA forecasts as a basis for long-term planning and about how quickly FAA needs to proceed with capacity-related improvements in its 1982 National Airspace System Plan (NASP).

Most other aviation forecasts generally support FAA's projections, but some do not. This is not surprising in light of the uncertainty about the factors that may affect future traffic growth. The Air Transport Association and a major aerospace firm have suggested that the U.S. airline industry may already be approaching its mature size, which would mean that air carrier operations may level off or even decline by the end of the century. Airline deregulation has destabilized market structure and airline profitability, leading to questions about the ability of the industry to finance badly needed new equipment. There are questions about the future price and availability of aviation fuel and about the long-term impacts of the Professional Air Traffic Controllers Organization walkout.

There is also uncertainty about the future distribution of operations among user groups and among airports. FAA expects general aviation users to account for 75 percent of the increase in demand, but there are large uncertainties about the continued growth of the general aviation fleet. One such uncertainty is the future price and availability of the aviation gasoline used by small personal aircraft. **As for air carriers, market forces and the restrictions imposed following the strike have already resulted in a redistribution of operations** away from congested hubs to second-tier airports that have excess capacity. **This new trend, in combination with improved facilities for general aviation traffic at reliever airports, could make it possible to accommodate** some increases in aggregated operations within existing system capacity.

AIRPORT CAPACITY ALTERNATIVES

At any given airport, delay occurs when demand for terminal airspace or runways approaches the capacity to handle aircraft safely. Some delay is normal and inevitable, especially during peak traffic hours or when capacity is reduced because of adverse weather. At some major airports, however, the level of demand is now such that delay is chronic and severe. These delays inconvenience passengers, increase airline operating costs, and waste over a hundred million gallons of fuel each year.

One way to deal with delay is to increase the capacity of hub areas, either by adding runways to an existing airport or by building a new airport to relieve other, overcrowded airports. Large amounts of land are required, however, and there are strong community objections to airport noise. These factors have made major airport construction and expansion rare in the past decade. In addition, building new runways or airports requires years of planning (and, in some cases, litigation) before it can be implemented. At some airports, however, independent "stub" runways for propeller aircraft could increase effective capacity and minimize land-use and noise problems.

A more immediate way to alleviate delay is to manage traffic so that demand fits within existing capacity. This could be done through **economic measures,** such as differential pricing schemes to help divert traffic from peak to off-peak hours, or perhaps from congested to underutilized airports. **Administrative measures,** such as hourly quotas or user restrictions, could induce a similar reallocation of demand.

Improved ATC technology could also help ease airport congestion. Automated terminal-area metering and spacing, to smooth and expedite the flow of traffic, and the Microwave Landing System, to permit more flexible use of crowded airspace close to the airport, might permit existing capacity to accommodate more operations. The magnitude of the potential benefits varies widely with local conditions, runway configuration, and traffic mix.

There is no single "best" way to increase capacity or reduce delay. A variety of measures—economic, administrative, and technological—will be needed and the optimum solution for any given airport will be determined largely by local conditions.

AIR TRAFFIC CONTROL

FAA is planning a program of technological improvements intended to enable the National Airspace System **to handle a higher volume of traffic with increased efficiency and safety.** This new technology will replace present equipment —some of which has been in use for over 40 years—with a **modern integrated system that will be more reliable and productive.** This should allow new or improved forms of service to be offered to airspace users. **Operating costs** should be lower than with the current generation of ATC equipment, but there would also be major capital cost requirements. Many of these improvements can be implemented during the next 10 years, but the full modernization program will not be completed until the late 1990's.

Two technologies are at the heart of the new generation of ATC: 1) advanced computers; and 2) a two-way digital data link between aircraft and the ground. Advanced high-speed computers and new software will permit the ATC system to improve the overall management of traffic flow, as well as to formulate tactical measures that will ensure conflict-free, expeditious, and fuel-efficient flight paths for individual aircraft. Replacement computers will be installed first in en route ATC centers, then in terminal areas, and finally in a central flow control facility that will manage air traffic on a national basis. **In addition to safety and capacity benefits, these computers will permit a level of automation in ATC that will greatly reduce the workforce** needed to handle future traffic loads.

The improved data link between aircraft and ground facilities will permit a rapid and extensive exchange of information and instructions without relying exclusively on voice radio for communication—for example, transmittal of clearances and weather information. **FAA also proposes to use this data link as the basis for the Traffic Alert and Collision Avoidance System (TCAS)** which will provide aircraft with an independent, airborne supplement to ground-based separation assurance.

In terminal areas, the use of **the Microwave Landing System (MLS) will provide more precise and reliable guidance for landing** in adverse weather conditions. **In combination with procedural changes, MLS could also lead to more efficient use of airport capacity** because it allows aircraft to follow any of several curving or segmented approach paths to the runway, thereby easing some of the constraint imposed by the present Instrument Landing System (ILS), which provides only straight-line guidance along a single path.

In general, OTA finds that the ATC system improvements proposed by FAA are **technologically feasible** and **desirable with respect to safety, capacity, and productivity,** although there are alternatives that might be equally effective. In most of the programs reviewed, **detailed cost and benefit information is not yet available, making it difficult to judge the cost effectiveness of the FAA proposals** in relation to the possible alternatives. For the same reason, it is **not yet fully clear whether the overall benefits will exceed the capital expenditures** needed to effect the improvements, **how the benefits will be distributed** among user groups, and how system cost will be allocated. Further information will be needed on implementation plans and specific costs and benefits throughout the Congress' consideration of the FAA's 1982 National Airspace System Plan.

Funding Issues

Based on information available at the end of 1981, OTA estimates that the costs of airport development grants-in-aid, modernization of ATC facilities and equipment, and related research and development could average roughly $1.5 billion per year over the next 10 years, about 50 percent higher than the level of recent years. **Congress has several options to provide funding for these programs.** One would be to cover these expenditures by **general fund appropriations.** This option, while it would afford the Congress continuing close control of FAA programs through the annual appropriations process, might not provide the assured continuity of funding needed for undertaking a 10-year program of the scope envisioned by FAA.

Alternative options involve **reestablishing, in one form or another, the Airport and Airways Trust Fund** which expired in October 1980. Possible approaches to reinstituting the trust fund include: 1) **a user tax structure and tax rates similar to those that existed before;** 2) **higher user tax rates—raised either uniformly or selectively by type of user;** or 3) **a different scheme of taxation that would levy fees in proportion to benefits received or costs imposed** by each type of airspace user.

All of these options are controversial, and the search for a solution is complicated by many long-standing issues about the equity of user charges and the appropriate distribution of trust fund revenues. Other issues that could emerge in the debate are **how to use the present uncommitted balance in the trust fund** (amounting to about $3 billion) and **whether to use trust fund moneys to help meet operating and maintenance costs.** In the past, trust fund allocations derived from user fees have covered only about 15 percent of these costs, and many feel that users should pay a larger share of them. Others argue that trust fund moneys should be reserved exclusively for capital improvements and R&D expenses.

RESPONSE TO FUTURE GROWTH

Basically, there are three forms of action that can be taken to affect growth: regulatory, economic, and technological. **Regulatory actions** include measures imposed by the Government that would restrict the use of airspace or the availability of ATC services according to user class or types of activity. **Economic measures** are those that would affect the cost of using the airspace or that would allow the market forces of competitive pricing to determine access to facilities and services that are in high demand. **Technological responses** include not only improved forms of ground-based and avionic equipment to increase the efficiency of airspace use, but also increases in airport capacity through the construction of new or improved landing facilities. **All three approaches are likely to be used; the issue is not which to adopt, but what combination and with what relative emphasis.** Ultimately, the measures adopted to deal with growth will reflect a more fundamental policy decision: **is growth to be accommodated wherever and whenever it occurs; or is it to be managed and directed so as to make the most effective use of existing resources, with the costs fairly borne by the beneficiaries.**

Chapter 2

INTRODUCTION AND OVERVIEW

Photo credit: Bill Osmun, Air Transport Association

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Chapter 2

INTRODUCTION AND OVERVIEW

BACKGROUND

The National Airspace System (NAS) includes about 6,500 public-use airports serving nearly all cities and small communities in the United States. Connecting these airports is a network of air routes, defined by navigational aids, that channel the flow of traffic. Flight along these routes, as well as operations in the terminal areas surrounding airports, is monitored and controlled by a system of ground-based surveillance equipment and communication links—the air traffic control (ATC) system.

With two exceptions (Washington National Airport and Dulles International Airport),* U.S. airports used by commercial flights are owned and operated by local, regional, or State authorities. Many general aviation (GA) aircraft also use these commercial air carrier airports, but most are served by smaller public airports and by roughly 10,000 privately owned fields. The air route system and the ATC system are operated by the Federal Aviation Administration (FAA), which has responsibility for assuring the safe and expeditious movement of aircraft in U.S. airspace and contiguous areas. FAA is also responsible for coordinating the use of airspace shared by military and civil aviation.

In all, the NAS accommodates about 180,000 operations (takeoffs and landings) per day at airports with FAA control towers, or roughly 66 million per year. Of these, 22 percent are commercial flights (scheduled air carrier, commuter, and air taxi), 74 percent are general aviation, and 4 percent are military. Most of the commercial operations are concentrated at the top 66 airports, which account for over 77 percent of commercial operations and 88 percent of passenger enplanements. Within this group, airline traffic is even more highly concentrated at a few major hubs. As shown in figure 1, the 10 largest hubs handle 33 percent of all operations and 47 percent of all passengers.[1]

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*Washington National and Dulles International are owned by the Federal Government and operated by the FAA.

[1] *FAA Statistical Handbook of Aviation, Calendar Year 1980* (Washington, D.C.: Federal Aviation Administration, 1981), passim.

TRENDS AND FORECASTS

The use of NAS, as measured by aircraft operations at airports with FAA towers, has grown at an annual rate of about 4 percent in recent years, due almost entirely to the rapid growth of the GA sector.[2] FAA expects the rate of growth to slow to about 3 percent per year in the next decade, but this would still mean that the congestion now experienced at the 5 or 10 largest airports may spread to 10 or 15 additional airports by the year 2000. This growth would also lead to substantial increases in the workload of the ATC system. FAA workload forecasts indicate that there may be both capacity* and safety problems arising from the growth in demand for ATC services, problems that will not be confined to major airports or commercial operations. Projections show the demand for ATC services by GA users could increase by as much as 70 percent over the next 10 years.

The accuracy of these forecasts depends on factors that are difficult to predict reliably. For example, the growth in aviation is extremely

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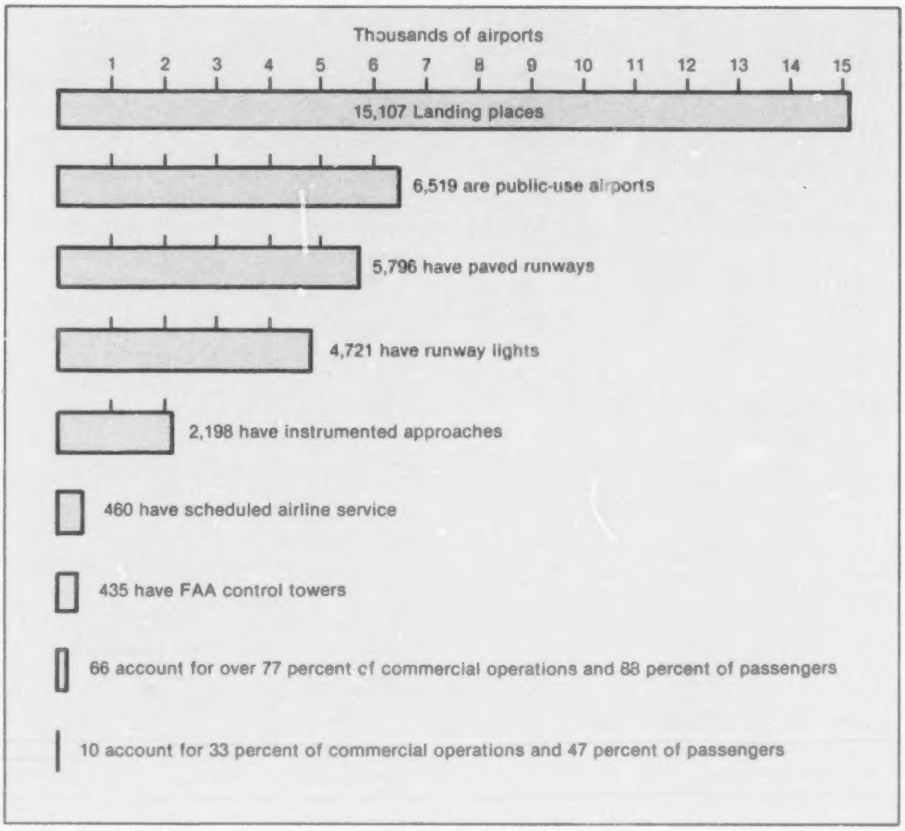
[2] *FAA Aviation Forecasts, Fiscal Years 1981-1992* (Washington, D.C.: Federal Aviation Administration, 1980), passim.

*In a general sense, capacity refers to the number of aircraft that can be *safely* accommodated in a given period of time. *Airport capacity* is defined as the maximum number of aircraft operations (takeoffs and landings) that can be accommodated in a given period of time on a given runway (or set of runways) under prevailing conditions of wind and weather and in conformance with established procedures for maintaining safe separation of aircraft. Similarly, *airspace capacity* is defined as the maximum number of flights that can be allowed to pass through a volume of airspace during a given period of time without violating minimum separation standards.

Figure 1.—Profile of U.S. Airports, 1980[a]



[a] Includes heliports, STOL ports, seaplane bases, and military-civil joint-use fields; excludes facilities in Puerto Rico, Virgin Islands, and Pacific Territories.

SOURCE: *FAA Statistical Handbook, 1980.*

sensitive to the state of the national economy. The price and availability of fuel could be a serious constraint on all classes of aviation. The long-term effects of airline deregulation are uncertain but they could have an important influence on the profitability and competitive structure of the industry. Thus, while there is a consensus that air activity as a whole will continue to grow, it is not certain how much growth to expect, where it will occur, or what strategies should be adopted to accommodate it. It does seem clear, however, that growth of aviation, even at a rather slow rate, gives rise to concern about future airport capacity, terminal area congestion, and the safety and efficiency of the ATC system.

Photo credit: Bill Osmun, Air Transport Association

A crowded terminal

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THE AIRPORT CAPACITY PROBLEM

Concentration of air traffic at a few large hubs, brought about by the economics of air transportation and by the general increase in air travel, creates congestion and delay.* The cutback in scheduled flights following the air traffic controllers' strike has caused the problem to abate temporarily, but congestion can be expected to recur when operations return to normal levels, and with it the associated problem of safely handling a growing volume of air traffic. Congestion results in delays that increase airline operating costs and, ultimately, the cost of air travel for the public. If fuel prices increase, the cost of these delays will become magnified. Commuter airlines and air taxi services are even more vulnerable to delay costs than trunk airlines, since they have a much smaller base of passengers across which to spread these costs. GA users of major hubs also feel the effects of delay in the form of restrictions on access to busy airports imposed during peak hours to deal with congestion.

Expanding airport capacity, either through construction of new airports or enlargement of existing ones, is an obvious but far from easy solution. The availability of land for airport expansion is severely limited in major metropolitan areas, and the cost of available land is often prohibitive. There is also rising community resistance to airport expansion and construction on the grounds of noise, surface congestion, and the diversion of land from other desired purposes. Even where these obstacles could be overcome, increasing capacity by building a new airport is at best a long-range solution—the leadtime from conception to beneficial use of a new airport is often a decade or more.

To deal with the problem of congestion in the near term, and in a less capital-intensive way, two management approaches may be used. One is to shift some of the demand for use of the airport from peak to offpeak hours by administratively imposing quotas or by applying differen-

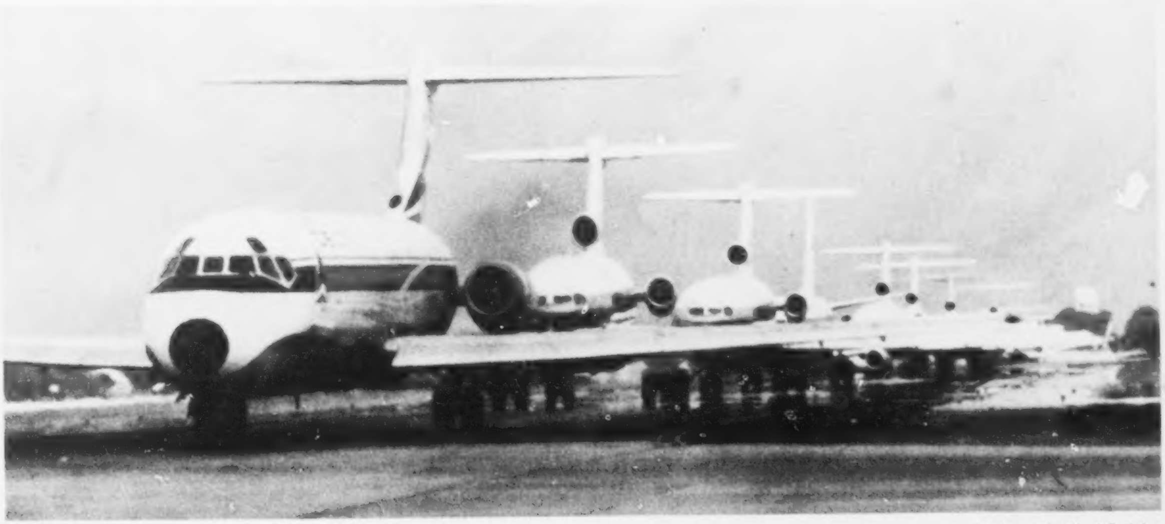

Photo credit: Neal Callahan

Congestion and delay

**Delay* occurs whenever aircraft must wait beyond the time they are scheduled to use an airport or a sector of airspace. In practical terms, delay is usually defined as occurring whenever some percentage of aircraft must wait longer than a specified period of time, e.g., 80 percent of the aircraft must wait 4 minutes or longer. *Congestion* occurs as demand (the desired number of operations) approaches capacity. An increasing number of aircraft seeking to use an airport or an airspace sector at the same time causes queues to build up among aircraft awaiting clearance to proceed.

tial pricing for airport access according to the time of day. This solution tends to work to the advantage of major air carriers and against the commuter and air taxi operators, and even more heavily against GA users, who complain that quotas or peak-hour pricing might effectively preclude them from using major airports at all. An alternative strategy is to divert some traffic to another airport—for example, from a large metropolitan hub to GA reliever airports in the vicinity. In several cities the problem is not a general shortage of capacity but a disproportionate demand at one airport, while excess capacity exists at nearby airports that could serve as satellites or relievers. The difficulty arises in determining who is to be diverted, since few potential users of reliever airports would willingly accept diversion, especially if it imposes inconvenience or extra cost. One way to make diversion more attractive would be to improve the ground transportation links between hubs and reliever airports.

The intractability of the congestion problem and the difficulties of increasing airport capacity or making more efficient use of capacity through managerial techniques have prompted some people to look to the ATC system for an alternate solution. Through procedural changes or technological improvements, the ATC system might be able to make more efficient use of the airspace in crowded terminal areas, thereby expediting the flow of traffic to and from runways.

THE ATC PROBLEM

The task of controlling air traffic in congested terminal areas is greatly complicated when traffic consists of a mixture of large and small, piston and jet aircraft. Arriving and departing traffic, which is descending and climbing along various paths and at different speeds to and from en route altitudes, may consist of a combination of IFR and VFR traffic.* This traffic mixture is inherently difficult to manage. Efficiency dictates that aircraft be moved to and from the runway as expeditiously as possible and that gaps in traffic be kept to a minimum. Safety, on the other hand, requires a regular traffic pattern to prevent conflicts, and a minimum safe separation distance to prevent fast aircraft from overtaking slower ones. Air turbulence in the form of wake vortices,** which are more severe behind heavier aircraft, requires even greater separation between aircraft than would be needed if all were a uniform size. The overall result is that ATC procedures necessary to assure safety and to manage the workload also contribute to delays in terminal areas.

Technological improvements to the ATC system could help make fuller use of the physical capacity of the airport and reduce controller workload. Among these improvements are new surveillance, communication, navigation, and data processing equipment that could enhance the controllers' ability to separate and direct traffic. The Discrete Address Beacon System (previously know as DABS and now designated as Mode S) is a new generation of radar equipment that permits aircraft to be interrogated individually for information about identity, position, and altitude. Mode S also provides a two-way data link that could reduce dependence on the present voice radio channels and provide a much more rapid and extensive exchange of information between air and ground. Various forms of proposed airborne systems to detect and avoid potential collisions would provide a supplement to present separation assurance techniques and reduce some of the controller's burden in handling a high volume of traffic. It may also be possible to provide computer analysis of flight plans in advance that would help resolve conflicts in terminal areas, expedite traffic flow, and permit more direct and fuel-saving routing from origin to destination. Another proposed improvement is the addition of special cockpit displays that would provide a picture of traffic in terminal areas and thereby permit pilots to cooperate more effectively with the controller or to assume some of the controller's present responsibility for separation assurance and determining flight path in terminal areas. Finally, the Microwave Landing System (MLS) would not only improve the ability to land in conditions of severely reduced visibility, but also permit multiple or curving approach paths to the runway instead of the single-file, straight-in approach required with the present Instrument Landing System (ILS). In the longer term, proposed new ATC technology might replace the present system of ground-based radar and radio navigation and surveillance capabilities.

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*Aircraft operating under Instrument Flight Rules (IFR) and Visual Flight Rules (VFR).

**Eddies and turbulence, generated in the flow of air over wings and fuselage, can upset the stability of following aircraft. Wake vortices, which are invisible, cannot now be accurately detected, and their movement and duration cannot be reliably predicted.

These proposed improvements, if adopted, would require very large investments over the next two decades. These investments would be made by the Federal Government, but some of the funds could be provided by taxes on airspace users, who might also have to purchase new avionics equipment to supplement or replace what they already have. Managing the transition to a new generation of ATC would also require careful attention, both to assure continuity of service and to avoid the penalities of excessive cost or unexpected delay. It therefore seems especially important to select an evolutionary path that does not foreclose options prematurely and does allow flexibility in the choice between competing technologies.

These prospective ATC improvements raise important issues for airspace users. If the required new avionics systems become mandatory for access to terminal areas or for general use of controlled airspace, some GA, small commuter,

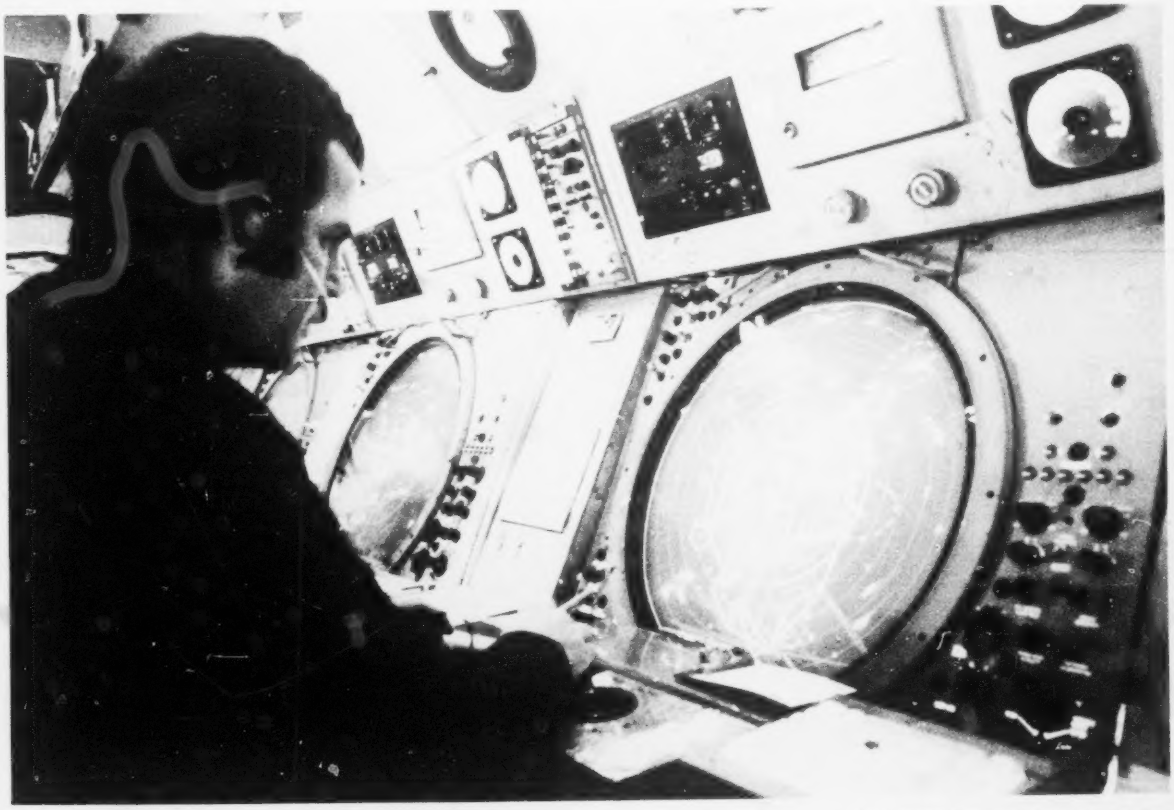

Photo credit: Federal Aviation Administration

Air controller and screen

and air taxi operators may find the cost prohibitive. New civil aviation requirements may not be entirely compatible with the missions or capabilities of military aircraft that share the airspace. There will probably be pressure to prolong the transition period and to retain as much of the present system as possible. Some possible improvements might ultimately have to be rejected, despite of their potential for increasing capacity or enhancing safety, because of the cost to users or infringement of the right of access to the airspace.

THE COMMITTEE REQUEST

Concerns about these problems and about the feasibility and cost of proposed solutions prompted the House Committee on Appropriations, Subcommittee on Transportation, to request that OTA undertake an assessment of airport and terminal area capacity and related ATC issues. Subsequently, the Senate Committee on Commerce, Science, and Transportation also expressed interest in these issues and endorsed the request of the House Committee on Appropriations.

Specifically, the Committee on Appropriations requested that OTA make an independent assessment in four major areas:

- scenarios of future growth in air transportation;
- alternative ways to increase airport and terminal area capacity;
- technological and economic alternatives to the ATC system modifications proposed by FAA; and
- alternatives to the present ATC process.

OTA'S APPROACH

This assessment considers the growth of air transportation over the remainder of this century. Particular attention is given to large hub airports, where most of the congestion and delay is expected to occur. For the ATC system, the assessment focuses on improvements that would affect the safety and capacity of terminal airspace, but developments in other parts of the ATC system (en route and flight information services) are also considered. Effects of these changes on airspace users (commercial operators, passengers, general aviation, and the military services) are also examined. Policy options and alternative development plans are identified and analyzed.

The results of this assessment are presented in the following five chapters:

Chapter 3. Description of the functions, organization, and operation of NAS with emphasis on ATC.

Chapter 4. Analysis of possible long-range trends in air activity and the effect they might have on technical, investment, and management decisions.

Chapter 5. Examination of prospective new technologies and organizational alternatives for the ATC system.

Chapter 6. Analysis of various ways to increase airport capacity and their advantages and disadvantages.

Chapter 7. Discussion of the policy implications that arise from alternative approaches to increasing airport capacity and improving the ATC system.

ISSUES

Expanding, improving, and maintaining the national system of airways, airports, and air traffic control has been an important objective of the Federal Government from the earliest days of aviation. There have been undeniable benefits to airspace users and the general public from the greater speed and regularity of air transportation and from the remarkable record of safety that has been achieved over the years. The rationale for Federal involvement in the development and operation of NAS has traditionally rested on two grounds: 1) promotion and regulation of interstate and foreign commerce; and 2) enhancement of the capability for national defense. It has been argued on both grounds that the Federal Government must take an active role to coordinate the development and to manage the operation of the system. The system that has evolved under Federal sponsorship and direction is not without its flaws, however, and some observers believe that future development should be directed along lines other than those of the past. Many of their concerns are embodied in the summary of major issues which follows; these issues will be treated in greater detail in subsequent chapters of the report.

Growth

There is basic agreement among aviation experts that civil aviation in the United States will continue to grow, thereby increasing the overall demand for airport use and ATC services. There is considerably less agreement about the rate of growth, the distribution among airspace users, the demands on various types of facilities and the kinds of services that will be required. As a result, there are sharp disputes about how to accommodate this growth or to influence the form and direction it may take.

FAA's projections have led it to conclude that severe capacity restrictions will manifest themselves in terminal areas and some parts of the en route system and that perhaps as many as 20 airports may be saturated by 2000. To accommodate this expected growth, the FAA proposes the addition of new airport capacity and ATC facilities designed to handle higher traffic volumes. However, past FAA forecasts have consistently projected higher rates of growth than have actually materialized, casting doubt on the current FAA forecasts and the expected demand for ATC services through the remainder of this century. Some observers see trends already developing in a different way. They argue that recent changes such as airline deregulation, the growth of commuter service, sharp rises in fuel cost, and slower economic growth will either dampen growth or cause it to develop in a pattern significantly different from that of the past. For example, one suggestion is that in an unregulated environment, market forces will cause a redistribution of traffic as users find that delay costs outweigh the benefits of operating at congested hub airports.

GA is the sector of aviation where growth has been the most rapid and where there is most serious concern about accommodating future demand. Twenty years ago, GA accounted for only a small fraction of instrument operations; today it represents slightly over half of all instrument operations at FAA facilities, and most forecasts show GA demand for ATC services increasing at rates far higher than those of commercial air carriers. Measures to restrict GA activity at major hubs or to divert it to reliever airports or offpeak hours are certain to be controversial. GA users feel that reservations, quotas, or differential pricing schemes, would unfairly deny them access to and use of the airspace system. On the other hand, some believe that GA flights into congested terminal areas should be limited because they typically carry very few passengers and so provide less public benefit than commercial aviation per operation or per unit of airspace use.

At a more general level, the prospects of traffic growth and capacity limitations raise the issue of strategic response to accommodating future demand. In the past, the approach has been essentially to accommodate demand wherever and whenever it occurred, i.e., the aim has been to foster growth in civil aviation. Some question whether this approach is still desirable, arguing that demand and the growth of air activity should be managed and directed in ways to make the most productive use of airspace and the most efficient use of existing facilities.

Basically, there are *three forms of action that can be taken to influence growth: regulatory, economic, and technological. Regulatory* actions include measures imposed by the Government that would control the use of the airspace or the availability of ATC services according to user class or types of activity. *Economic* measures are those that would affect the cost or price of using the airspace or that would allow market competition to determine access to facilities and services that are in high demand. *Technological* responses include not only improved forms of ground-based and avionic equipment to increase the efficiency of airspace use, but also increases in airport capacity through construction of new or improved landing facilities. *All three approaches are likely to be used, and the issue is not which to adopt but what combination and with what relative emphasis.* Ultimately, the choice of measures will reflect a more fundamental strategic decision about how to meet increasing demand. Chapter 4 presents a further discussion of future growth, and chapters 5 and 6 examine the various responses to growth.

Technological Improvements

The many technological improvements of the ATC system being contemplated by FAA fall into four classes:

- navigation and guidance systems;
- surveillance;
- communication; and
- process improvements.

These potential improvements have three major characteristics: 1) most are technologically sophisticated and require further development and testing before they can be operationally deployed; 2) they will entail very large expenditures by the Federal Government to put them in place and—in most cases—additional costs to airspace users who will have to equip their aircraft with special avionics; and 3) many years will be required for full deployment.

There are several controversial aspects of these technologies. First, there are purely technical and engineering questions that need to be answered: will these new systems work as intended, what are their advantages and disadvantages compared to existing technology, and how can their development be managed so that options are not foreclosed prematurely? As decisions are made and implementation proceeds, it will be necessary to coordinate the program carefully in order to provide an orderly transition and to avoid the costs that could result from delay or unexpected technical setbacks.

Beyond these technical and managerial matters, there are more fundamental questions about the role of FAA in planning and carrying out technological programs of this nature. Congress, for example, has questioned FAA's proposed handling of the program for modernization of its en route computer system, as have other members of the aviation community. They are concerned that FAA is not consulting adequately with specific user groups and not taking advantage of relevant expertise available outside the aviation community. Some of them foresee a time when air traffic may have to be curtailed simply because the technology to handle increased traffic with an acceptable level of safety has not been properly planned, developed, and deployed.

On the other side, there are those who defend FAA's general strategy for ATC modernization and approve the way in which particular technological programs are being handled. They argue that deployment must proceed at a cautious pace both because of the enormous uncertainties that must be overcome and because there must be continuity of operations throughout the transition. In their view, the potential consequences of abrupt changes or premature decisions are more serious and, in the long run, more harmful to aviation than temporary curtailments that may have to be imposed while technological difficulties are being resolved.

Chapter 5 examines some of the technological issues surrounding proposed system improvements, and chapter 7 addresses strategy and policy options for managing the transition.

Control Philosophy

Perhaps the most fundamental issue underlying the proposed improvements in the ATC system is that of control philosophy—the principles that should govern the future operation of the system. The philosophy of the present system for controlling IFR traffic is embodied in three operational characteristics: the system is primarily ground-based, highly centralized, and places great emphasis on standardized (i.e., predict-able) behavior by airspace users. In contrast, VFR traffic has little contact with the ATC system, except with flight service stations and control towers at airports, and operates much as it did in the early days of aviation, even though it shares airspace with IFR traffic in some instances.

As ATC technology evolved the locus of decisionmaking under IFR began to shift from the cockpit to the ground. Routes were determined by the placement of ground-based navigation aids; surveillance was accomplished by reports to ground centers and later by search radar; and observers in airport towers began to direct aircraft in landing and takeoff patterns. As the density of air traffic increased, ground-based ATC personnel began to take more and more control over the altitude, route, and speed to be flown. To some extent this transfer of responsibility was the inevitable consequence of the technology employed, but organizational reasons also dictated ground-based control. Decisions concerning not the movement of individual aircraft but the pattern of traffic as a whole can best be made by a single person who is in a position to observe all flights operating throughout a volume of airspace over a span of time. Coordination and direction of several aircraft required that a single individual have authority over others—a role that the pilot of a single aircraft could not be expected to assume or that other pilots would accept.

Ground basing implies concentration of control at relatively few locations, and the trend has been for centralization to increase over time. Again, the reasons are both technological and organizational: centralization is organizationally advantageous because it consolidates functionally similar activities and allows technical specialization, both of which lead to greater efficiency and reliability of operation. For example, en route traffic in continental U.S. airspace is now controlled from 20 regional centers (ARTCCs), and proposed ATC system improvements would lead to even further consolidation, with en route and terminal control eventually merging into a single type of facility. A similar trend toward centralization can be observed in FAA's plans to consolidate flight service station activities at about 60 sites, compared to the present dispersion at over 300 locations.

Perhaps the best example of the trend toward centralization is the growing importance of the Central Flow Control (CFC) facility at FAA headquarters in Washington, D.C., which acts as a nerve center for the entire airspace system. With the aid of computers, CFC reviews the national weather picture and anticipated aircraft operations for the coming day and determines the incidence and cost (extra fuel consumed) of delays that could occur because of weather and air traffic demand. This results in a daily operational master plan that smooths demand among airports and allows delays to be taken on the ground at the point of departure rather than in holding patterns at the destination. The value of this capability was demonstrated when capacity quotas were imposed as a consequence of the August 1981 air traffic controllers' strike. CFC allowed a national airspace utilization plan to be developed, with detailed instructions to airports and en route centers on how to manage traffic and minimize the adverse effects of the capacity restrictions.

A system characteristic that accompanies ground-based centralization of control authority is standardization of performance. FAA operating procedures specify the behavior of pilots and controllers in every circumstance, which increases the reliability of system operation by reducing uncertainty and by routinizing nearly every form of air-ground transaction. Safety is the prime motivating factor, but capacity and efficiency are also highly important considerations. Controller workload is reduced when the range of possibilities they have to deal with is limited, and this in turn permits a given volume of traffic to be handled with less stress or, alternately, an increase in the number of aircraft each controller can safely handle. Either way, the efficiency of the ATC system (measured in terms of hourly throughput or controller productivity) is increased, with a corresponding reduction in system operating cost.

Despite the advantages of ground-basing, centralization, and standardization, there are complaints about the control philosophy of the present system. Pilots complain that a ground-based system detracts from their control over the conduct of the flight. Centralization may also be a problem if, by concentrating control facilities or flight services, the personnel on the ground are less able to provide particularized instructions or to take action based on localized knowledge of flight conditions. Standardization, by definition, limits the flexibility of response and the freedom to pursue individual or special courses of action.

The prospective changes in ATC technology are viewed with mixed feelings by airspace users and air traffic controllers. Technology that would increase the level of automation could, on one hand, promote greater centralization and standardization of control functions and could lead to increases in safety, capacity, or efficiency. On the other, automation could serve to increase ground authority still further and to reduce the flexibility of the system in dealing with nonroutine events. Technology like collision avoidance systems or cockpit displays of traffic information could give back to the pilot critical information (and hence control responsibility) and might enhance the pilot's ability to cooperate more effectively with the ground-based controller. At the moment, these devices are thought of as backups in the event of controller or system error, but their prospective use also raises the possibility of independent pilot actions that might contravene controller instructions or disrupt the overall pattern of traffic.

Chapter 5, which deals with these and other forms of advanced aviation technology for ground-based and airborne application, treats the issues that arise from prospective changes in distribution of control between the air and the ground or from further centralization of ATC functions and services.

Freedom of Airspace Use

The rising demand for ATC services and the prospect of congestion at more and more major airports are the basic stimuli for many of the technological improvements and procedural changes now being sought by the FAA. However, the very measures that might ease capacity problems or assure the safety of high-density airspace are often controversial with some categories of users because they are perceived as infringements on their freedom to use NAS. GA users feel particularly threatened, but air carriers and commuter airline operators have also voiced concern. The military services as well are wary of some new forms of ATC technology and the procedures that may accompany their use because they may interfere with military missions or be incompatible with performance requirements for combat aircraft.

As the complexity of ATC technology has increased, so has the amount of equipment that must be carried on the aircraft and the amount of controlled airspace from which VFR flight is excluded unless the aircraft is equipped with a transponder to allow identification and tracking by the ATC system. Restrictions on airport use, especially at large and medium hubs, have also grown more confining for VFR flights, and the airspace around many of the busiest airports is now designated as a "terminal control area" in which all aircraft are subject to air traffic control and may operate only under rules and equipment requirements specified by FAA. GA, the principal user of the VFR system, finds itself pressured in several ways. Uncontrolled airspace is shrinking and may disappear altogether; it is becoming increasingly difficult to use metropolitan airports because of equipment requirements; and the cost of equipping the aircraft with IFR avionics and acquiring an instrument rating are often out of economic reach for the personal GA pilot. Prospective technological improvements—such as the Traffic Alert and Collision Avoidance System (TCAS), data link, or MLS—are viewed by many GA users as further restrictions on their access to airports and airspace. Many of them feel that, while this new technology may be desirable or even necessary for air carriers and larger business aircraft, it should not be required of all GA users or made a prerequisite for IFR services or access to commercial airports.

Commuter airline operators share some of these GA concerns. Virtually all commuter and air taxi operators are equipped for IFR operation and find their needs well served by the present

ATC technology. They see little further advantage in new technology and are concerned about the expense of having two sets of equipment serving the same purpose—advanced avionics needed for a high-density terminal at one end of the flight and present-day equipment that may be useful for many years to come at small community airports. They are also concerned that the more advanced avionics might eventually lead to more restrictive rules of operation or access to terminal areas. Thus, many commuter and air taxi operators would favor a dual-mode system that allowed them to retain their present IFR avionics even though more advanced forms were in use by other types of aircraft operators.

Military aviation operates under the civil ATC system in all shared airspace and under military control in areas restricted to military use. In flying through civil airspace to and from training areas, military aircraft must often follow circuitous routes or observe altitude and speed restrictions that lengthen transit time. The military services would prefer an arrangement that allows more direct access to training areas and avoids operation in mixed airspace. Air carriers have a different view: the most direct routes for trunk airlines are often blocked by restricted military areas, and the air carriers argue for procedures that would allow them to traverse these areas in the interest of shortening flight time and saving fuel.

Another issue has to do with new technology that might be adopted for civil aviation, which in most cases would be extra equipment for military aircraft. For combat aircraft, particularly fighters, the space for avionics and antennas is often at a premium. While careful coordination of military and civil requirements can eliminate some of these problems, certain basic incompatibilities are likely to remain and to produce continuing controversy.

The issues of freedom of airspace access and use are discussed further in chapter 5 in connection with specific forms of new aviation technology.

Automation and Controller Functions

Despite the vast complex of ground-based equipment and facilities for surveillance, communication, and data processing, ATC remains a highly labor-intensive activity. FAA is keenly aware of this and has sought for some time to find ways to automate selected ATC functions. However, most of the automation that has been instituted so far has been to assist air traffic controllers rather than replace them. Decisionmaking and communication—two major elements of controller workload—have not been automated to any appreciable degree, and the ratio of controller work force to aircraft handled has remained relatively constant. In addition, the present method of backup to automated control functions involves reversion to manual procedures used in the previous generation of ATC equipment; this method of assuring service in the event of outages has tended to perpetuate the team size and staffing patterns of the previous generation.

Plans for an advanced generation of ATC call for automation of several manual controller functions: conflict prediction and resolution, terminal area metering and spacing, flight plan approval and issue of clearances, and communicating routine control instructions to individual aircraft. Such forms of automation could lead to substantial increases in controller productivity and might eventually provide the basis for a more extensively automated system in which most routine control functions are carried out by computers, with the human controller acting in the role of manager and overseer of machine operation.

This path of evolution raises three important groups of issues. First, there are questions about the feasibility and advisability of replacing the human controller to such an extent. ATC now relies heavily on judgment and awareness of the dynamics and subtleties of the air traffic situation. Some observers doubt that all of these characteristics could be dependably incorporated into computer software in the foreseeable future. The proponents of automation argue that much of the routine, repetitive, or predictive work of ATC is ideally suited to computers, and that an incremental approach to automation will help solve many of the problems since each new step can build on successful previous advances.

A second major set of issues is the reliability of automated systems and the backup methods to be used when the inevitable equipment failures occur. Experience with the present automated ATC equipment indicates that computer failure rates are a cause for concern, and the loss of computer-supplied data may mean that ground personnel lose effective control of traffic until manual backup procedures are instituted—a process that may take several minutes to complete. Computer experts maintain that equipment and software reliability can be greatly improved and that automated systems can be designed to be more failure tolerant. These experts also contend that present experience with manual procedures as backups to outages of automated equipment indicates a fundamental flaw in design philosophy because the proper backup to an automated system is not manual operation, but another automated system. Critics of automation question the acceptability of a system in which the human controller has no effective means of intervening in degraded states of operation.

A third issue is whether some of the responsibility that now resides with the ground-based system ought not to be transferred to, or at least shared with, the cockpit. A pilot in an aircraft equipped with an airborne collision avoidance system and a display of the immediately surrounding air traffic might be in a superior position to select the appropriate maneuver in case of conflict; in effect, such an airborne system would create a mode of IFR operation similar to the present VFR system. The chief disadvantage of this concept is that it could lead pilots to make a series of short-term tactical responses that might not be consistent with the overall scheme of managing traffic in congested airspace. In this case, the ground system would still have to act in the capacity of referee, and some contend that it would be better to keep all control of individual flight paths under one authority.

Chapter 5 contains a further examination of the issue of automation in connection with the discussion of the proposed en route computer replacement program and the mechanization of the Mode S data link and TCAS systems.

Funding and Cost Allocation

The expenditures that are likely to be required for ATC system improvements over the coming years could be considerably higher than those of past years. For the period 1971 to 1980, the amounts budgeted for facilities and equipment (F&E) and associated research, engineering, and development (RE&D) have averaged $397 million and $106 million respectively (in constant 1980 dollars).[3] Future improvements of the en route and terminal area ATC system and related programs for flight service station, navigation, and communication facility modernization may call for spending at twice this annual level or more. At the same time, operating and maintenance (O&M) costs are expected to rise, at least until modern labor-saving equipment is installed and productivity gains begin to be realized.

Since creation of the Airport and Airways Trust Fund in 1970, FAA has had two sources of funding. F&E, RE&D, and airport grants-in-aid have been covered wholly by appropriations from the trust fund. In addition, the trust fund has covered about 15 percent of O&M expenses, although this proportion has varied considerably from year to year. The balance of O&M costs, about $1.9 billion per year (1980 dollars), and all other FAA budget items have been from general fund appropriations. Overall, trust fund outlays have met about 40 percent of annual FAA expenses. The major source of revenue for the trust fund has been a tax levied on domestic and international airline passengers (see fig. 2).

In October 1980, the Airport and Airways Development Act expired, and Congress declined to pass reauthorizing legislation. At that time the trust fund had an uncommitted balance of

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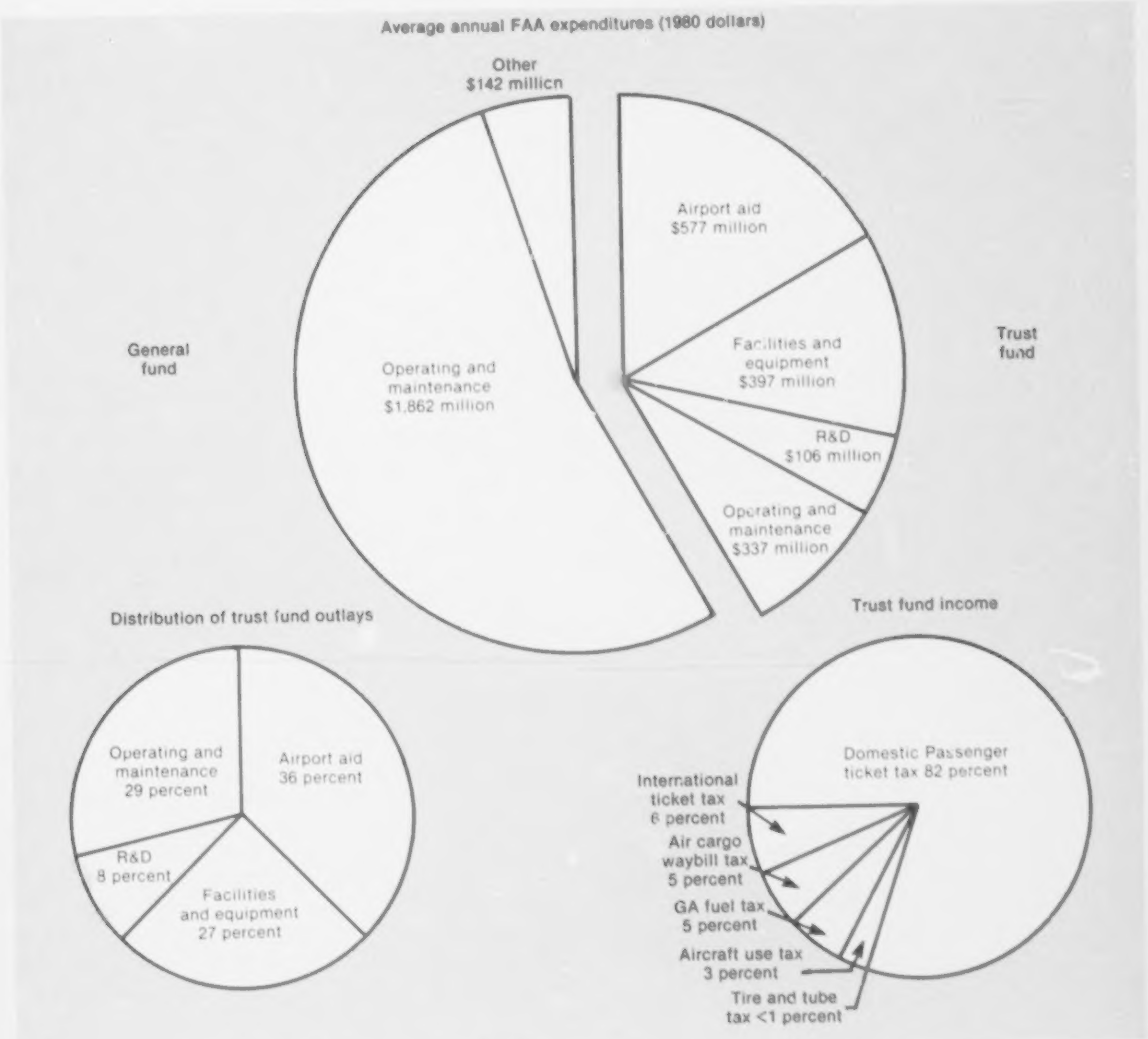
[3] OTA calculations based on FAA budget data, 1971-80.

Figure 2.—FAA Budget and Funding Sources, 1971-80



SOURCE: Office of Technology Assessment, based on FAA budget data, 1971-80.

$2.9 billion, the equivalent of about 2 years' expenditure at the then prevailing rate. Since that time some of the user taxes contributing to the trust fund have still been collected (but at reduced rates of taxation), and these revenues have been deposited partly in the General Fund and partly in the Highway Trust Fund. If these revenues are included and if authorizations from the trust fund during fiscal year 1981 are deducted, the uncommitted trust fund balance stood at roughly $3 billion at the beginning of fiscal year 1982.

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In considering sources of funding for future airport and ATC system improvements, Congress will encounter three broad and long-standing areas of controversy. In the absence of a trust fund or some other form of user charges to support capital improvement programs, these parts of the FAA budget would have to be funded from general revenues, which is certain to raise the issue of whether civil aviation and the airport and ATC system should be subsidized by the general public. The argument that the recipients of a service should pay the costs for the Federal Government to provide that service (a position strongly supported by the present administration), holds that capital improvements of facilities and equipment and the O&M costs of running the airport and ATC system should be borne by airspace users through various specific taxes. On the other hand, it can be argued that civil aviation, like other modes of transportation, provides a general benefit and therefore deserves support with public moneys. Other modes of transportation receive subsidy from the Government, and some members of the aviation community contend that there is no justification for singling out civil aviation for full recovery of capital and operating costs.

The resolution of this issue that has prevailed for the past 10 years has been a combination of special users taxes and General Fund financing, with the former going for capital expenditures and a small share of operating costs and the latter for the balance of FAA costs. A perpetuation of this scheme, through reestablishment of the Airport and Airways Trust Fund, could embroil Congress in another issue—what is the "fair" amount to be paid by various user classes. Most people concede that each user should pay roughly in proportion to the cost that they impose on the system, but there is violent disagreement within the aviation community as to what these costs are and how they are to be reckoned. Cost allocation studies conducted by the Department of Transportation and the FAA have generally concluded that, under the tax structure that existed before October 1980, commercial aviation paid nearly all (88 percent) of the cost of services provided to them. On the other hand, general aviation taxes returned at almost one quarter of allocated costs.[4] GA representatives have disagreed strongly with these findings, arguing that there is a substantial public benefit of aviation that has been undervalued in these cost allocation studies and that GA is charged for facilities and services that are neither required nor used by a major part of GA operators. Congress has shown little inclination to alter the user charge structure, and most of the proposed legislation to reestablish the trust fund would have little effect on the distribution of user charges that existed previously.

The third area of controversy concerns how the collected levies should be applied to costs. By congressional action, the use of trust fund moneys is restricted largely to capital expenditures and research and development activities, with some contribution toward operating expenditures. There are two major points at issue: 1) how should expenditures for capital improvements be allocated between airports and ATC facilities and equipment (and among airports and ATC facilities used by various types of aviation); and 2) should the allocation be broadened to cover a substantial part (or perhaps all) of O&M costs.

Resolution of these issues will become especially important when FAA presents its long-range plan for ATC system improvement. Increased expenditures for facilities and equipment and associated R&D will be called for, and operating expenses will probably remain high. FAA will be seeking a long-term commitment and an assured source of funding, but it will face strong opposition from segments of the aviation community if paying for FAA's programs and operating costs entails an increase in user taxes or a reallocation of the share to be borne by various classes of airspace users.

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[4] J. M. Rodgers, *Financing the Airport and Airway System: Cost Allocation and Recovery*, FAA-AVP-78-14 (Washington, D.C.: Federal Aviation Administration, November 1978).

Chapter 3

THE NATIONAL AIRSPACE SYSTEM

Photo credit: U.S. Department of Transportation

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Chapter 3

THE NATIONAL AIRSPACE SYSTEM

The National Airspace System (NAS) is a large and complex network of airports, airways, and air traffic control (ATC) facilities that exists to support the commercial, private, and military use of aircraft in the United States. This chapter examines the major parts of the system, both to see how the system operates and to identify factors that may shape its future development. For explanatory purposes, it first considers the goals of the system and then describes the system under three major headings: airports, air traffic services, and airspace users.

GOALS

NAS is designed and operated to accomplish three goals with respect to civil aviation:

1. safety of flight;
2. expeditious movement of aircraft; and
3. efficient operation.

These goals are related hierarchically, with safety of flight the primary concern. The use of airport facilities, the design and operation of the ATC system, the flight rules and procedures employed, and the conduct of operations are all guided by the principle that safety is the first consideration.

Without compromising safety, the second goal is to permit aircraft to move from origin to destination as promptly and with as little interference as possible. This involves preventing conflicts between flights, avoiding delays at airports or en route, and eliminating inefficient or circuitous flight paths. It also entails making maximum use of airport and airway capacity in order to satisfy demand, so long as safety is not compromised. If safety and capacity utilization are in conflict, the Federal Aviation Adminstration's (FAA) operating rules require that the volume of traffic using the system be reduced to a level consistent with safety.

The third goal is to provide airport and ATC services at low cost. This entails minimizing the costs to users—not only monetary costs but also the penalties of delay, inconvenience, or undue restriction. It also entails operating the system as efficiently as possible so as to reduce transaction costs and to increase productivity, i.e., to handle more aircraft or to provide better service to those aircraft with a given combination of runways, controllers, and ATC facilities.

Whereas safety cannot be compromised in the interest of cutting costs, capacity and cost may be traded off for the sake of safety. The special measures adopted to deal with disruption of the system as a result of the air traffic controllers' strike in August 1981 illustrate the hierarchal relationship of safety, capacity, and efficiency. In order to continue safe operation in the face of work force reductions, the number of aircraft allowed to use certain crowded airports and air ways at peak demand hours was reduced to a level that could be handled safely. These measures reduced capacity (the number of aircraft that the system could accommodate) and increased cost (delays, canceled flights, adherence to quotas), but an effort was made to allow the remaining capacity to be used effectively and keep costs within reasonable limits. For example, limits on the number of air carrier flights were imposed only at the 22 busiest airports, and restrictions were later eased at those airports where more operations could be accommodated. Airlines were allowed to use larger aircraft so as to provide as much seat capacity as possible but with fewer flights, and wherever possible flow control procedures were employed to ensure that aircraft were delayed on the ground rather than in flight, so as to minimize waste of fuel. Other restrictive measures were applied to cut back on general aviation (GA) flights. The military services voluntarily reduced flight operations.

The anticipated growth of air traffic and the demand for ATC services over the next two decades poses several problems, and the need to maintain a dynamic balance among system goals motivates the search for improved methods of ATC and better utilization of airway and airport capacity. Before turning to examination of these problems, however, it is first necessary to look at the major parts of the NAS and to consider the factors that could shape their course of development.

AIRPORTS

Airports are the first major part of NAS. They are any place designed, equipped, or commonly used for the landing and takeoff of aircraft. This definition covers a broad variety of sites: many of the sites designated as airports by the FAA are merely dirt strips or seaplane moorings near open water; at the opposite end of the spectrum are complex air terminals serving major metropolitan areas, like the 5,000-acre JFK International Airport in New York. About 60 percent of the 15,000 U.S. airports are private or military fields and not available for public use. Of the roughly 6,500 civil airports open to the public, almost 90 percent are used exclusively by small GA aircraft. The remaining 780 airports (about 5 percent of all U.S. airports) are served either by scheduled air carriers or by commuter and air taxi operators (see table 1).

FAA, in compliance with the Airport and Airway Development Act of 1970, maintains a master list of airport development needs for the next decade. This compilation, which is periodically revised, is known as the National Airport System Plan (NASP). It identifies categories of airports that are of Federal interest and that are eligible for Federal funds under the Airport Development Aid Program (ADAP), and the Planning Grant Program administered by FAA. NASP categorizes public use airports according to the type of aviation activity they accommodate: international, domestic air carrier, commuter, reliever, and general aviation. This does not imply that GA aircraft use only GA airports; in fact, there are GA operations at all categories of airports. Rather, the GA classification denotes that such airports serve only GA and not other types of users.

International Airports

An international airport regularly serves air carrier flights operating between the United States and foreign countries. International airports tend to be among the best equipped airports in terms of runways, landing aids, and ATC facilities. In 1980 there were 76 such airports.

Table 1.—Airports Included in National Airport System Plan, 1980[a]

Type of service	Conventional	Heliport	Seaplane	Total
Air carrier[b]	603	1	31	635
Commuter	139	—	6	145
Reliever	155	—	—	155
General aviation	2,198	4	22	2,224
Total NASP airports	3,095	5	59	3,159
Total public-use airports not in NASP[c]				3,360
Total				6,519

[a] Includes airports in Hawaii and Alaska.
[b] Includes 76 airports designated as ports of entry.
[c] Entirely general aviation.

SOURCE: Federal Aviation Administration, *National Airport System Plan, 1980-89*, 1980.

Domestic Air Carrier Airports

In 1980, NASP included 603 airports served by domestic air carriers, a figure that includes all of the international airports described above but excludes 1 heliport and 31 seaplane facilities served by scheduled air carriers. These airports are classified by FAA according to the size of the traffic hub they serve, where a hub is defined as a Standard Metropolitan Statistical Area (SMSA) requiring air service. The hub classifications are:

Hub classification:	*Percentage of total airline passengers**
Large (L)	1.00 or more
Medium (M)	0.25 to 0.99
Small (S)	0.05 to 0.24
Nonhub (N)	less than 0.05

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*Passengers enplaned by domestic and foreign carriers at U.S. airports.

A hub may have more than one air carrier airport, and the 25 SMSAs presently designated as large hubs are served by a total of 38 air carrier airports. The distribution of aviation activity at domestic air carrier airports is highly skewed, with progressively greater percentages of flights and passengers concentrated at fewer and fewer airports. In 1980, for example, the 486 nonhubs handled only 3 percent of all passenger enplanements; the 76 small hubs handled 8 percent; the 41 medium hubs handled 18 percent; and the 25 large hubs handled 70 percent. To carry this point one step further, the top five air carrier airports (Chicago, Atlanta, Los Angeles, Denver, and Dallas/Fort Worth) handled about one-quarter of all passenger enplanements and one-fifth of all airline departures. This means that air traffic congestion tends to center at a very small fraction of airports; but because of the volume of traffic handled at these airports, it affects a large percentage of all aircraft and passengers.

Photo credit: Federal Aviation Administration

All filled up

Photo credit: Federal Aviation Administration

Room to grow

Commuter Airports

Until the Airline Deregulation Act of 1978, many commuter and air taxi airlines were not certificated as scheduled air carriers by the Civil Aeronautics Board (CAB), and NASP classified airports served exclusively by commuter and air taxi in a separate category. Since airline deregulation, the number of airports in this category has fluctuated widely, showing sharp increases in 1979 and 1980 as commuter airlines sought to open up new markets and an almost equally sharp drop in 1981 as these markets failed to materialize. Commuter airports, typically located in small communities, handle a very low volume of traffic, 2,500 to 5,000 passenger enplanements per year. The major concern about this category is not capacity but keeping the airport in operation so as to provide essential air service for the small communities in which they are located.

Reliever Airports

Reliever airports are a special category of GA airport whose primary purpose is to reduce congestion at air carrier airports in large and medium hubs by providing GA users with alternative operational facilities and aircraft services of roughly similar quality to those available at hub airports. The criteria for classification as a reliever airport in NASP are 25,000 itinerant operations or 35,000 local operations annually, either at present or within the last 2 years. The reliever airport must also be situated in a SMSA with a population of at least 500,000 or where passenger enplanements by scheduled airlines are at least 250,000 annually. There were 155 airports designated as relievers in the 1980-89 NASP.

General Aviation

GA airports are either private use or public use, but only the latter are eligible for Federal development or improvement funds under NASP. There were approximately 2,200 GA public-use airports in the 1980 NASP. Capacity is usually not a concern except at the largest GA airports, such as Long Beach, Van Nuys, Teterboro, or Opa-Locka, which may require improvements similar to those contemplated at major hub airports. For most GA airports the chief concern is upgrading and extending airport facilities and ATC services so as to accommodate larger and more sophisticated aircraft and to allow operation under adverse conditions. These improvements are being sought both to support the expected growth of GA and to provide facilities comparable to air carrier airports, thereby permitting diversion of some GA operations from congested hubs.

AIR TRAFFIC SERVICES

The ATC system—the second major part of the National Airspace System—offers three basic forms of service: navigation aid (including landing), flight planning and in-flight advisory information, and air traffic control.

Navigation

Aid to navigation was the first service provided to civil aviation by the Federal Government. At the end of World War I, the Post Office undertook to set up a system of beacons along the original airmail routes to guide aviators at night and in times of poor visibility. By 1927, this airway extended from New York to San Francisco, with branches to other major cities.

In the 1930's, ground beacons for visual guidance were replaced by two types of low-frequency radio navigation aids—nondirectional beacons and four-course radio range stations. The nondirectional beacon emitted a continuous signal that allowed the pilot to navigate, in a manner analogous to using a light ground beacon, by homing on the signal with an airborne direction finder. The radio range station was a further improvement in that it emitted a directional signal, forming four beacons alined with respect to the compass, each defining a course. Pilots listened to a radio receiver and followed these radio beams from station to station along the route. The four-course radio range system was phased out beginning in 1950, after reaching a maximum deployment of 378 stations. Low-frequency nondirectional radio beacons are still in limited use in the United States and widespread use in other parts of the world.*

The technology that supplanted the low-frequency four-course range as the basic navigation system for civil aviation was very high frequency omnirange (VOR) transmitters, which were first put in service in 1950. This system had several advantages over low-frequency radio. VOR is less subject to interference and aberrations due to weather; it is omnidirectional, permitting the pilot to fly on any chosen radial rather than only the four courses possible with the radio range station; and the addition of a cockpit display freed the pilot from the need to listen to radio signals continuously. The major disadvantage of VOR is that signals are blocked at the horizon, and navigational signals from a station can be received over a much smaller area than low-frequency radio. To provide the same geographical coverage as the older low-frequency radio system, therefore, a great many more VOR stations were required. At present, there are 1,039 VOR stations in operation (930 FAA, 42 military, 67 non-Federal), providing extensive but not complete coverage of the contiguous 48 States and Hawaii and limited coverage of Alaska.

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*In 1981, there were 1,095 nondirectional radio beacons in service in the United States, including 54 military and 734 non-Federal installations.

In the 1960's, the basic VOR system was supplemented by distance measuring equipment (DME) that permitted measurement of range as well as direction to a station. The DME used the distance-measuring portion of a military Tactical Control and Navigation System (TACAN), colocated with a VOR station to create what is called a VORTAC. This is the standard airway navigation aid in use today, and at present all commercial air carriers have VOR/DME equipment.* Over 80 percent of GA aircraft are also equipped with VOR receivers, and over one-third of these also have DME. In addition to the Federal investment in VORTAC facilities (on the order of $250 million), there is a very large private investment (roughly $300 million) in airborne navigation equipment to use the present VORTAC technology. As a result, both the Federal Government and the aviation community have a strong incentive to protect this investment by prolonging the operational life of their VORTAC equipment and the airway route structure based on it.

Nevertheless, VOR—which relies on 30- or 40-year-old technology—has some inherent disadvantages. Because it is a ground-based system, it does not provide coverage of oceanic areas. Because it is a line-of-sight system, VOR is of limited usefulness at low altitudes or in mountainous areas. The VOR route structure concentrates traffic along rather narrow channels and produces a potential for conflict at intersections where airways cross. Further, navigation from one fix (intersection) to the next does not always produce the most direct routing from origin to destination.

Several alternative navigational systems (developed principally for military aviation) are available, and some are already used in auxiliary applications by civil aviation. The *Omega* system, developed by the U.S. Navy, is a low-frequency radio system that provides global coverage. It has been purchased by some airlines for transoceanic flights. *Loran-C* (also low-frequency radio), operated by the Coast Guard, is a maritime navigation system that also covers most of the continental United States; it affords very good accuracy and low-altitude coverage, even in mountainous areas. Some airline and corporate jet aircraft have self-contained airborne navigation systems such as *Doppler radar or Inertial Navigation System (INS)*, which are accurate and are usable worldwide. All of these new systems permit *"area navigation" (RNAV)*, whereby the pilot can fly directly between any two points without restriction to a VOR airway. There are also available RNAV systems that permit the aircraft to follow direct routings using VOR as a reference.

Many commercial air carriers and more than 7 percent of GA aircraft (largely business and corporate aircraft) have RNAV capability. Since 1973, FAA has been gradually implementing RNAV routes in the upper airspace and instituting approach procedures at selected airports to accommodate aircraft equipped with such systems. Phasing out the current airways structure and converting to a more flexible system of area navigation is a process that will require many years to complete. At present, FAA is committed to upgrading VORTAC stations to solid-state equipment at a cost of roughly $210 million (fiscal year 1980 dollars) over the next 10 years. At the same time, FAA must face the question of adopting new navigation technology to conform to new international standards scheduled for consideration by the International Civil Aviation Organization in 1984. The issue is not so much selection of a single new navigation system to replace VORTAC as it is a question of adopting procedures for worldwide navigation

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*Military aircraft are equipped with TACAN, VOR/DME, or both.

(especially RNAV) that will be compatible with several possible technologies.

Landing Aids

A guidance system for approach and landing is simply a precise, low-altitude form of navigation aid with the additional accuracy and reliability needed for landing aircraft in conditions of reduced visibility. The standard system now in use, the Instrument Landing System (ILS), was first deployed in the early 1940's although a prototype system was first demonstrated by James Doolittle in 1929.

ILS provides guidance for approach and landing by two radio beams transmitted from equipment located near the runway. One transmitter, known as the localizer, emits a narrow beam alined with the runway centerline. The other transmitter, the glide slope, provides vertical guidance along a fixed approach angle of about 3°. These two beams define a sloping approach path with which the pilot alines the aircraft, starting at a point 4 to 7 miles from the runway. Because the ILS is generally not accurate or reliable enough to bring the aircraft all the way onto the runway surface by instrument reference alone, the pilot makes a transition to external visual reference before reaching a prescribed minimum altitude on the glide slope (the decision height). The decision height varies according to the airport and the type of ILS installation: 200 feet for most airports (category I), but 100 feet on certain runways at some airports (category II). At present there are 708 category I and 44 category II ILS installations in commission in the United States.* FAA plans call for installation of ILS at additional sites, primarily commuter airports, and for modernization of some 250 existing sites by converting to solid-state equipment and, in the process, upgrading 69 of them to category II capability.

ILS has two major limitations, both of which affect airport capacity. First, since the ILS does not provide reliable guidance all the way to touchdown, there are times and conditions when the airport must be closed. Such severely reduced visibility occurs less than 1 percent of the time for U.S. airports as a whole, but when this happens at a busy airport, traffic can be backed up not only at the affected airport but also at alternate landing sites and at airports where traffic originates. The other limitation is that it provides only a single fixed path to the runway—in effect, a conduit extending 4 to 7 miles from the runway threshold through which all traffic must flow. This has an even greater affect on capacity. When visibility is such that the ILS approach must be used, traffic must be strung out along a single path and the rate at which landings can be effected is constrained by the speed and spacing of aircraft in single file.

The Microwave Landing System (MLS), which has been under development by FAA for several years and is now ready for initial deployment, could overcome these limitations of ILS, which in turn could help improve the flow of traffic in terminal areas by allowing more flexibility in segregating and sequencing the arrival of aircraft on the runway. The magnitude of the resulting capacity gains is subject to some dispute, however, and not all agree that MLS would play a major part in reducing terminal airspace congestion. The MLS is discussed further in chapter 5.[1]

Flight Planning and Advisory Information

Timely and accurate information about weather and flight conditions is vital to airmen, and FAA perceives this aspect of system operation to be a prime benefit, particularly to the GA community. Flight planning and information services take several forms and are provided partly by FAA and partly by the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce. NOAA publishes maps, aeronautical charts, and related documents from information furnished by the FAA. The National Weather Service of NOAA provides weather maps and reports. FAA publishes manuals, instructions, and notices to airmen (NOTAMs) to help pilots in planning and executing flights. FAA operates a national weather teletype network, disseminates weather information by radio broadcast and recorded telephone messages, and provides weather briefings. FAA also disseminates to airmen, both preflight and in flight, information concerning the status of navigation aids, airport conditions, hazards to flight, and air traffic conditions. FAA personnel are also available to help pilots in preparing and filing flight plans and to disseminate these flight plans to other ATC facilities along the intended route and at the destination.

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*In addition, there are 48 non-FAA facilities that have category I ILS installations.

[1] *Microwave Landing Transition Plan,* APO-81-1 (Washington, D.C.: Federal Aviation Administration, 1981).

All of these planning and advisory services are intended to guide the airman in making use of the airspace under either of two basic sets of rules—Visual Flight Rules (VFR) and Instrument Flight Rules (IFR)—which govern the movement of all aircraft in the United States.* In general, a pilot choosing to fly VFR may navigate by any means available to him: visible landmarks, dead reckoning, electronic aids (such as VORTAC), or self-contained systems on board the aircraft. If he intends to fly at altitudes below 18,000 ft, he need not file a flight plan or follow prescribed VOR airways, although many pilots do both for reasons of convenience. The basic responsibility for avoiding other aircraft rests with the pilot, who must rely on visual observation and alertness (the "see and avoid" concept).

In conditions of poor visibility or at altitudes above 18,000 ft, pilots must fly under IFR. Many also choose to fly IFR in good visibility because they feel it affords a higher level of safety and access to a wider range of ATC services. Under IFR, the pilot navigates the aircraft by referring to cockpit instruments and by following instructions from air traffic controllers on the ground. The pilot is still responsible for seeing and avoiding VFR traffic, when visibility permits, but the ATC system will provide separation assurance from other IFR aircraft and, to the extent practical, alert the IFR pilot to threatening VFR aircraft.

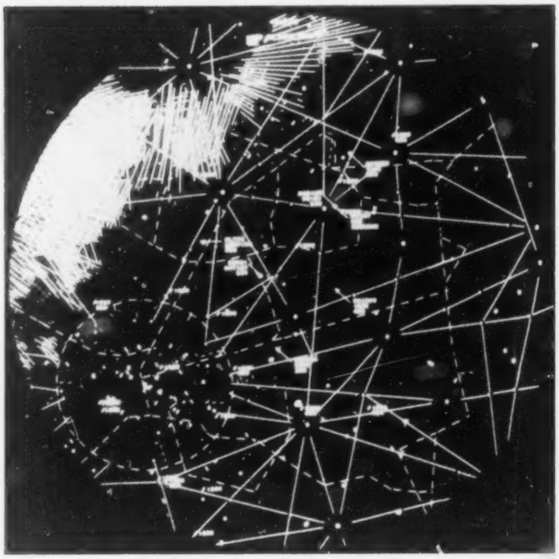

Photo credit: Federal Aviation Administration

A display of air traffic as it appears to a controller

The distinction between VFR and IFR is basic to ATC and to the safe and efficient use of airspace, since it not only defines the services provided to airmen but also structures the airspace according to pilot qualifications and the equipment their aircraft must carry. VFR flights over the contiguous 48 States may not operate at altitudes above 18,000 ft, which are reserved for IFR flights. The altitudes between 18,000 and 60,000 ft are designated as positive control airspace; flights at these levels must have an approved IFR flight plan and be under control of an ATC facility. Airspace above 60,000 ft is rarely used by any but military aircraft. Most of the airspace below 18,000 ft is controlled, but both VFR and IFR flights are permitted.

The airspace around and above the busiest airports is designated as a terminal control area (TCA) and only transponder-equipped aircraft with specific clearances may operate in it regardless of whether operating under VFR or IFR. All airports with towers have controlled airspace to regulate traffic movement. At small airports without towers, all aircraft operate by the see-and-avoid principle except under instrument weather conditions. Figure 3 is a schematic rep-

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*Similar visual and instrument flight rules are in force in foreign countries that are members of the International Civil Aviation Organization (ICAO). In many cases, ICAO rules are patterned on the U.S. model.

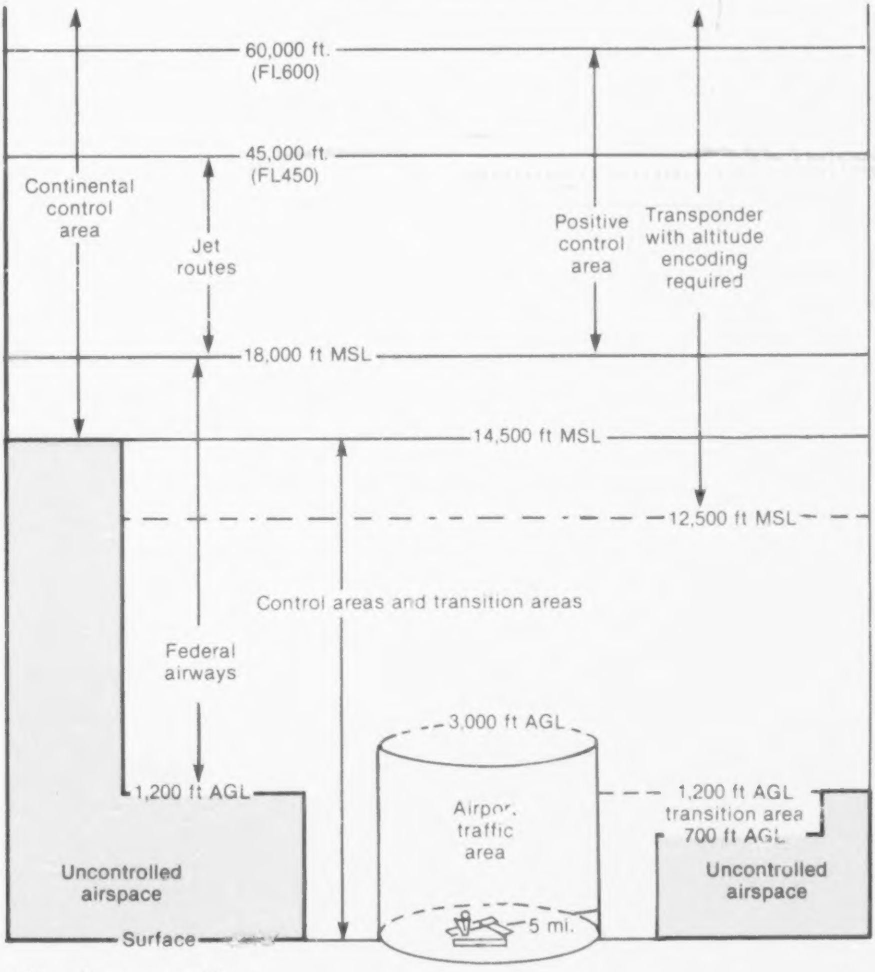

Figure 3.—Airspace Structure

60,000 ft.
(FL600)
45,000 ft.
(FL450)
Continental control area
Jet routes
Positive control area
Transponder with altitude encoding required
18,000 ft MSL
14,500 ft MSL
12,500 ft MSL
Control areas and transition areas
Federal airways
3,000 ft AGL
1,200 ft AGL
Airport traffic area
1,200 ft AGL transition area
700 ft AGL
Uncontrolled airspace
Uncontrolled airspace
Surface
5 mi.

AGL - Above ground level
MSL - Mean sea level
FL - Flight level

SOURCE: Federal Aviation Administration.

resentation of the resulting airspace structure; as the general rule, VFR flights are permitted everywhere except in positive control airspace although clearances are required to operate within TCAs and at airports with control towers.

The IFR/VFR distinction also governs avionics and pilot qualifications. A VFR flight taking off and landing at a small private field and flying only in uncontrolled airspace needs little or no avionic equipment, although a pilot must have a radio if he elects to file a VFR flight plan or land at an airport with a control tower. Aircraft flying under IFR, on the other hand, are required to have radio and avionics equipment that will allow them to communicate with all ATC facilities that will handle the flight from origin to destination. They must also be instrumented to navigate along airways and to execute an IFR approach at the destination airport. These requirements apply to all IFR aircraft, and Federal Air Regulations also specify additional

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equipment requirements and pilot qualifications for various classes of air carrier aircraft. In addition, both IFR and VFR aircraft must have transponders that automatically transmit their identity and altitude when they are in TCAs* or at altitudes above 12,500 feet.

The VFR/IFR distinction also determines the type of ATC facility that will provide service to airspace users. There are three general types of facilities operated by FAA: air route traffic control center (ARTCC), which serve primarily IFR traffic; airport traffic control towers, which serve both IFR and VFR aircraft; and flight service stations (FSS), which primarily serve VFR traffic.

FSS serves three primary purposes: flight planning and advisory information for all GA aircraft; the dissemination of flight plans (VFR and IFR) to other facilities along the intended route; and operation of teletype networks to furnish information on weather and facility status to civil and military users. FAA encourages but does not require pilots flying VFR to file a flight plan; IFR flights must file a flight plan and obtain clearance to use the airspace. Personnel are on duty to provide direct briefings and assistance in filing flight plans (counter service), but most FSS contacts are by telephone or by radio. If a VFR flight encounters weather or restricted visibility en route, the pilot (provided he is rated for instrument flight) can change to an IFR flight plan while in the air and be placed in contact with the ATC system. The FSS handles these requests and coordinates changes with towers or ARTCCs.**

FSS personnel are also ready to aid VFR pilots who experience in-flight emergencies. If a pilot is lost, the FSS will assist him by means of direction-finding equipment or arranging for tracking by an ATC radar facility. FSS personnel provide weather reports to pilots aloft and receive and relay pilot reports on weather and flight conditions. In more serious cases, such as engine trouble or forced landing, the FSS will attempt to pinpoint the location and coordinate search and rescue operations. Flight service stations also make periodic weather observations and transmit this information by teletype network to other ATC facilities and U.S. weather reporting services. Thus, FSS is essentially a communications center, serving general aviation directly but also providing information services for all airspace users. Figure 4 illustrates the communication links and the types of facilities that are in contact with a typical FSS.

FAA operates 317 FSSs, mostly at airports with VORTAC installations. Since traffic operates out of thousands of airports, much of FSS's work is done by means of transcribed messages and standardized briefings. The importance of FSS as an onsite facility at airports may thus be diminishing, and FAA has plans to consolidate FSSs into about 60 centralized locations. Concurrent with the reduction in the number of FSSs, FAA plans to increase the amount and type of on-call and remote services, including methods for semiautomatic filing of flight plans. FSS personnel would, however, be available—but usually at a remote location—to provide emergency services or to provide direct assistance to airmen. This proposed consolidation of FSS facilities has been the subject of controversy in the aviation community because it is feared that the quality and extent of services might be diminished and that observations for the National Weather Service might be curtailed.

Air Traffic Control

The essential feature of air traffic control service to airspace users is separation. The need for this service derives from the simple fact that, under IFR conditions, the pilot may not be able to see other aircraft in the surrounding airspace and will therefore need assistance to maintain safe separation and reach his destination. Historically, this need came about gradually with the increasing use of the airspace as the airlines began to operate under instrument flight conditions in the 1930's. In 1934 and 1935, the airlines organized a system for controlling traffic within roughly 100 miles of Newark, Chicago, and

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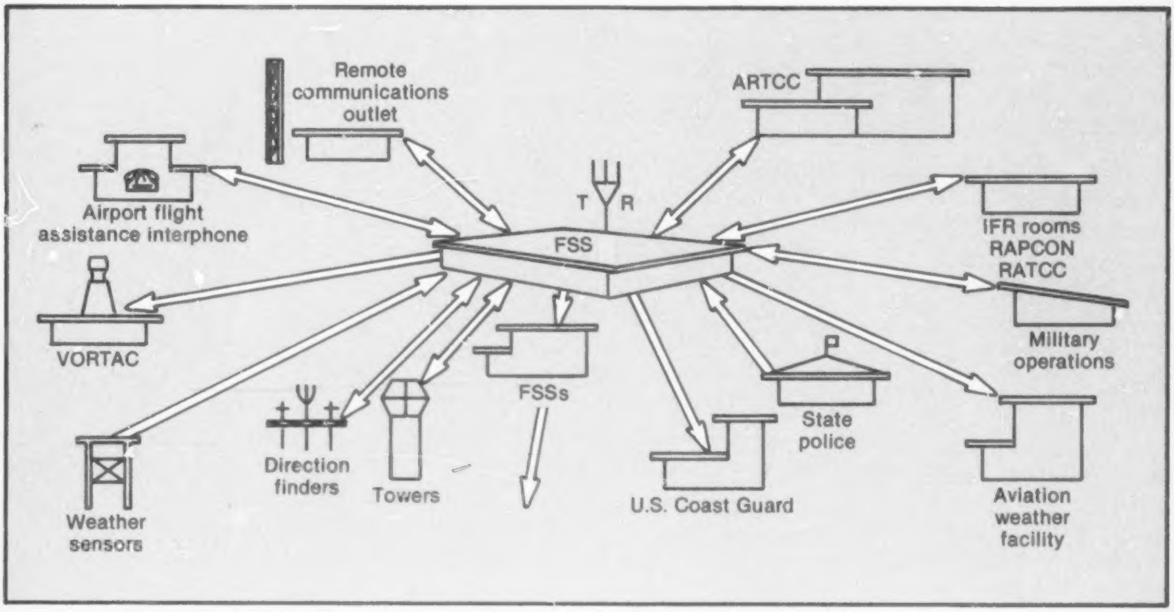
*Altitude-encoding transponders (Mode C) are required only in Group I TCAs, of which there are nine at present.

**In the interest of reducing controller workload, this service was suspended following the controllers' strike in August 1981.

Figure 4.—Typical Flight Service Station Communication Links



SOURCE: Federal Aviation Administration

Cleveland. In 1936, the U.S. Government assumed responsibility for these centers and established five more "airway" centers within the following year.

This "first generation" of separation service relied solely on radio and telephone communication. At established points along the airways, pilots were expected to report their time of arrival and altitude and their estimated time of arrival over the next checkpoint. In the ATC center controllers wrote the message on a blackboard and tracked flights by moving a marker on a tabletop map. In a later improvement, paper strips marked with flight data were posted in the order of their estimated arrival at each reporting point or airway intersection. This flight-strip system is still available as a backup system in the event of radar surveillance equipment failure, since it requires only radio communication between the pilot and the controller. To provide direct pilot-controller contact, especially as traffic density grew, it became necessary in the 1950's to establish remote communication air-ground stations at distances over 100 miles from ATC centers to relay messages from pilots to the controller handling their flights. This greatly improved the safety, capacity, and efficiency of the control process. In the first generation system, aircraft flying in the same direction and altitude were kept 15 minutes apart in their estimated arrival times at reporting points. This separation standard depended on the accuracy of position information and—equally important—on the speed and reliability of communicating instructions to resolve potential conflicts. Since the capacity of the ATC system increases as separation standards are reduced, progress therefore depended on further improvements in both communications and surveillance equipment as the ATC system developed.

The second generation of separation service came with the introduction of radar after World War II. In the 1950's, airport surveillance radars (ASRs) were introduced at major airports to provide data on arriving and departing aircraft within roughly 50 miles* At about the same time, the Civil Aeronautics Authority (predeces-

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*FAA now operates 195 ASRs.

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sor to FAA), in coordination with the Air Force, began purchasing long-range (200-mile) radars for the en route centers with a view to establishing complete radar coverage of the continental United States. This was completed in 1965, with the exception of some gaps in low-altitude coverages, and today data from multiple radar sites are relayed to ATC centers, so that radar contact can be kept with almost every IFR flight. The introduction of radar allowed continuous monitoring of actual aircraft progress and the detection of potential conflicts or hazard situations. The controller, under a process known as "radar vectoring," could direct aircraft away from thunderstorms, around slower aircraft or downwind for spacing in the approach area. In so doing, however, the controller began to preempt control of heading and altitude from the pilot for short periods of time. Radar separation standards were greatly reduced from those of the first generation: 3 miles on approach or about 2 minutes at piston aircraft speeds.

Despite these improvements, there were still two major deficiencies in a surveillance system that relied on raw radar return: the altitude of the aircraft was not measured; and the identity of the aircraft could not be established from radar return alone. In 1958, the newly formed FAA began development of a so-called "secondary" radar surveillance system in which the radar beam, as it rotated in the scan of azimuth, triggered a positive, pulsed-code reply from a "transponder" (or beacon) on board the aircraft. This pulse contained information on the identity and altitude of the aircraft which could be correlated with primary radar return. This development program, known as Project Beacon, led to adoption of the secondary radar system in 1961, and it is the standard surveillance method in use today for separation assurance. All commercial air carriers and about two-thirds of GA aircraft are now equipped with transponders* and the primary radar system has become a backup for use in the event of equipment malfunction. The introduction of transponders and the simultaneous development of digitized information systems and computer-driven traffic displays led to a reduction of controller workload. Automated flight plan processing and dissemination, introduced at about the same time, further reduced controller workload by facilitating handoffs of aircraft from one en route sector to another and between en route and terminal area controllers. Collectively, these technological changes constitute the third generation of air traffic control.

All of these improvements have simplified and speeded up the acquisition of information needed to provide separation service, but they have not substantially altered the decisionmaking process itself, which still depends upon the controller's skill and judgment in directing aircraft to avoid conflicts. In recent years, attempts have been made to automate the decisionmaking aspects of separation assurance or to provide a backup to the controller in the form of computer-derived conflict alerts. Computers can now perform a simplistic conflict alert function by making short-term projections of aircraft tracks and detecting potential conflicts that the controller may have missed. Since the technique depends upon all aircraft being equipped with transponders, however, it does not provide separation assurance between unequipped aircraft.

The introduction of two-way digital communication rather than voice would mark the beginning of a new generation of separation service. In 1969, the Air Traffic Control Advisory Committee recommended the introduction of an improved form of radar known as the Discrete Address Beacon System (DABS). This system provides selective identification and address and a two-way, digital data link that allows improved transmission of data between ground and aircraft, so that much of the routine ATC information can be displayed in the cockpit for the pilot. DABS would thus provide more complete and rapid exchange of information than the present voice radio method. DABS would improve separation service in other ways as well. It could provide more accurate position and track data and could lead to more comprehensive forms of automated conflict detection and resolution. Further, because DABS can interrogate aircraft selectively it can avoid the overlap of signals in areas of high traffic density.

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*Slightly less than 30 percent of GA aircraft have altitude-encoding (Mode C) transponders.

Another method for providing improved separation assurance is by means of collision avoidance systems on board the aircraft, which would alert the pilot to converging aircraft and direct an avoidance maneuver. Airborne collision avoidance systems, while conceived as a backup to ground-based separation service, would effectively transfer back to the IFR pilot some of the see-and-avoid responsibility that now governs VFR flight. Still another approach to separation assurance is the use of techniques to meter or space the movement of aircraft traffic into terminal areas from the en route portion of the system. These are strategic rather than tactical measures, in that they are directed not at avoiding conflicts per se but at preventing the congested conditions in which conflicts are more likely to occur. Traffic metering, spacing, and sequencing techniques are now used by controllers to prevent traffic buildup or undesirable mixes of aircraft, but for some time FAA has been seeking to develop automated methods that will accomplish this smoothing and sorting of traffic flow without intervention by controllers. Success of these efforts will depend upon development of computer prediction and resolution routines that will detect conflicts among flight plans (rather than flight paths) and issue appropriate instructions before actual conflict occurrs.

SYSTEM ORGANIZATION AND OPERATION

The third major part of the National Airspace System is the facilities and operational procedures for managing air traffic.

ATC Sectors

From the controller's viewpoint, the ATC system is made up of many small sectors of airspace, each defined in its horizontal and vertical extent and each manned by a controller with one or more assistants. Each sector has one or more assigned radio frequencies used by aircraft operating in the sector. As the flight moves from sector to sector, the pilot is instructed to change radio frequencies and establish contact with the next controller. On the ground, the controller must perform this "hand off" according to strict procedures whereby the next controller must indicate willingness to accept the incoming aircraft and establish positive control when the pilot makes radio contact before relieving the first controller of responsibility for the flight.

Since the number of aircraft that can be under control on a single radio frequency at any one time is limited to roughly a dozen, sector boundaries must be readjusted to make the sectors smaller as traffic density grows. At some point, however, resectorization becomes inefficient; the activity associated with handing off and receiving aircraft begins to interfere with the routine workload of controlling traffic within the sector. To help manage this workload, the sectors around busy airports are designed in such a way that arriving or departing traffic is channeled into airspace corridors, in which aircraft are spaced so as to arrive at sector boundaries at regular intervals. While this procedure facilitates the task of air traffic control, it results in longer and more fuel-consuming paths for aircraft, which have to follow climb and descent paths that are less than optimal. To this extent, the performance characteristics of the ATC system aggravate the effects of congestion in busy airspace and detract from the overall efficiency of airspace use.

ATC Facilities

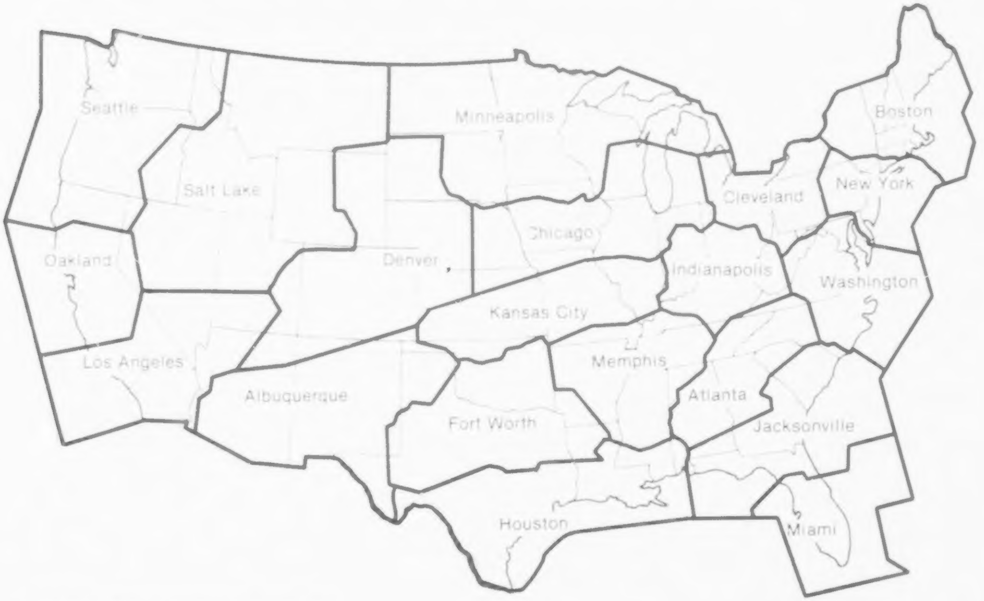
Organizationally, the facilities that control air traffic are of three types: en route centers, terminal area facilities (approach/departure control and airport towers), and flight service stations. The first handles primarily IFR traffic; terminal area facilities and flight service stations handle both IFR and VFR flights. In addition, flight service stations perform information collection and dissemination activities that are of systemwide benefit.

The en route portion of the ATC system consists of 20 ARTCCs,* each reponsible for a major geographic region of the continental United States (see figs. 5 and 6). An ARTCC contains between 12 and 25 sectors which control traffic on the airways within the region, and ARTCC airspace is further divided into low-altitude sectors primarily used by propeller aircraft and high-altitude jet sectors. When aircraft are in level cruise, management of traffic is relatively simple and problems are infrequent. The sectors that are difficult to control are those where flights are climbing or descending around a major airport. Since these en route sectors are feeding aircraft into and out of terminal areas, the task of control also becomes complicated if the airport is operating near capacity. En route controllers may be required to delay the passage of aircraft out of their sector in order to meter traffic flow into terminal areas.

At smaller airports, aircraft leaving control of an ARTCC pass directly to control by the airport tower. At major hubs, however, there is an intermediate ATC facility called terminal radar approach control (TRACON) located at the airport. The TRACON (or "IFR room") handles arriving and departing traffic within roughly 40 miles of the airport—sequencing and spacing arrivals for landing on one or more runways, and sometimes at more than one airport. The TRACON also vectors departing aircraft along climbout corridors into en route airspace. The approach and departure controllers at a TRACON exercise a high degree of control over aircraft and must monitor the progress of each aircraft closely, as well as coordinate their activities with the ARTCCs from which they are receiving traffic and with the towers that are handling the takeoffs and landings at the airport itself.

Tower personnel control the flow of traffic to and from the runways and on ramps and taxiways connecting to the terminal. Tower controllers are the only ATC personnel that actually have aircraft under visual observation, although at larger airports they rely heavily on radar for surveillance. Figure 7 illustrates the activities of

Figure 5.—Air Route Traffic Control Center Boundaries



SOURCE: Federal Aviation Administration.

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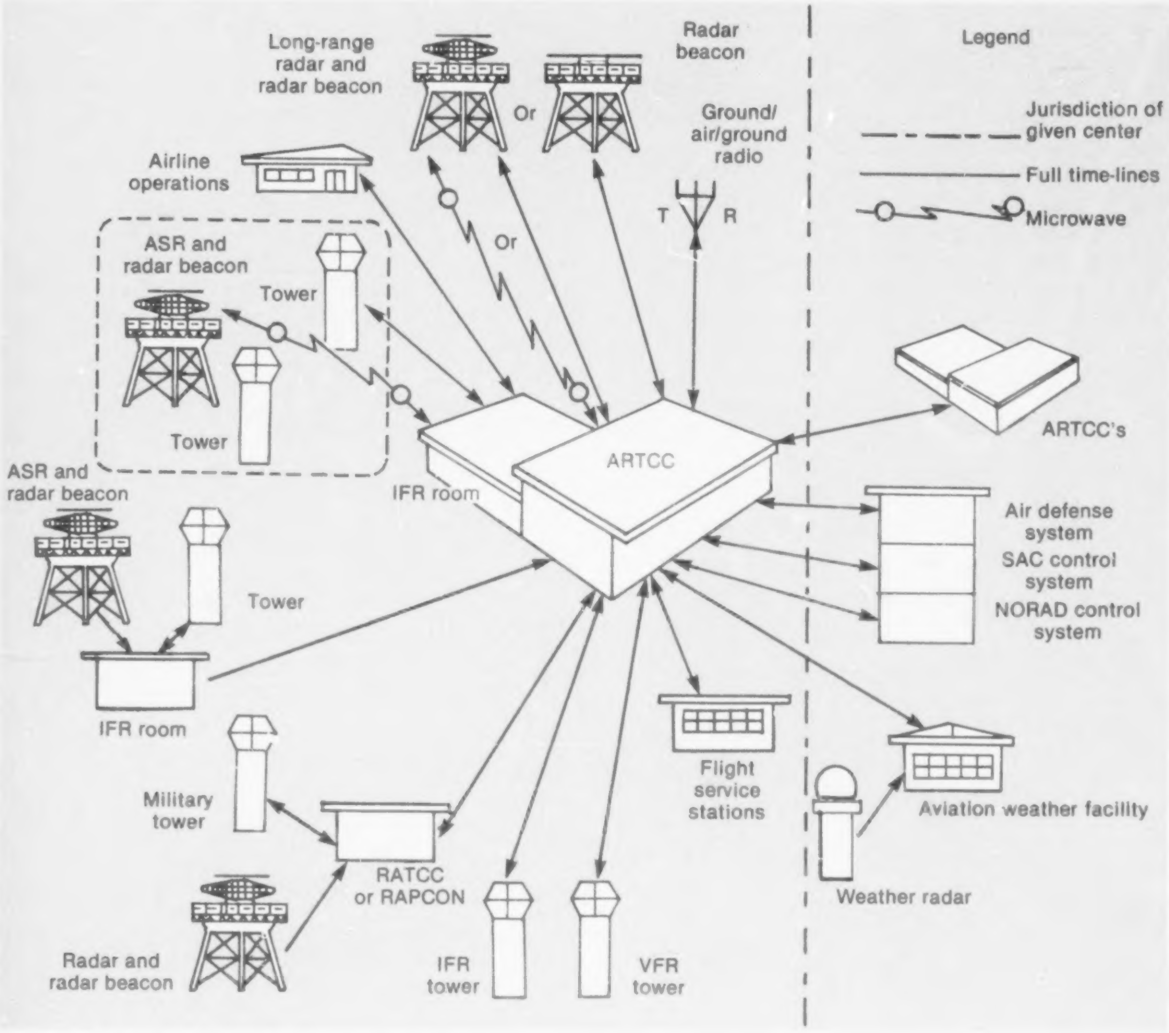
*In addition, there are two ARTCCs located outside the continental United States, in Hawaii and Puerto Rico.

Figure 6.—Connections of a Typical ARTCC With Other Facilities


Long-range radar and radar beacon
Or
Radar beacon
Ground/ air/ground radio
T
R
Legend
Jurisdiction of given center
Full time-lines
Microwave
Airline operations
ASR and radar beacon
Tower
Or
Tower
ARTCC
IFR room
ARTCC's
ASR and radar beacon
Tower
Air defense system
SAC control system
NORAD control system
IFR room
Military tower
Flight service stations
Aviation weather facility
RATCC or RAPCON
Weather radar
Radar and radar beacon
IFR tower
VFR tower

SOURCE: Federal Aviation Administration

ATC terminal and en route facilities handling a typical IFR flight.

There are currently 431 airports with towers operated by FAA, of which 234 are approach control towers and the remainder are nonapproach control towers. An approach control tower, with its associated TRACON, provides separation and instrument landing services for IFR traffic and is also responsible for integrating VFR traffic into the approach pattern. Figure 8 illustrates the equipment and facilities typically available at a large airport with an approach control tower. A nonapproach control tower is responsible for assisting traffic by providing weather, traffic, and runway information for all arrivals (VFR or IFR), but does not provide ILS or separation assurance.

Airspace Users

The users are the fourth major part of the National Airspace System. They cover a wide spectrum in skill and experience, types of aircraft

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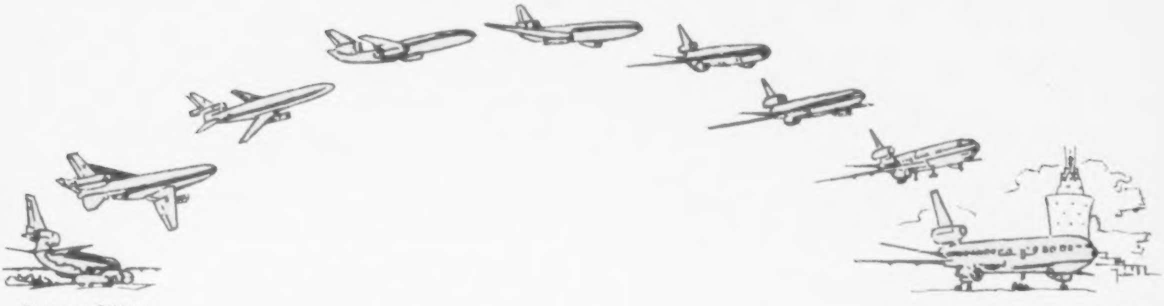
Figure 7.—ATC Activities for a Typical IFR Flight


Chicago O'Hare International Airport
La Guardia Airport, New York City

At the departure gate, pilot confirms altitude, speed, route and estimated flight time with controller in the Chicago tower at O'Hare. After flight clearance, pilot contacts Chicago ground control for taxiing instructions and proceeds to runway.

When ready for takeoff, pilot once again contacts controller in the Chicago tower who, using radar and his own view from the tower, clears airplane for takeoff.

One mile away from takeoff point, the controller in the Chicago tower transfers responsibility for the flight to a departure controller, also at O'Hare airport, who directs the pilot to the proper course for the first leg of the flight.

Thirty miles farther in the flight, the departure controller transfers responsibility by instructing the pilot to contact a particular controller at the en-route Chicago Center, located in Aurora, Ill.

The controller at Chicago Center tracks the plane as it climbs to approximately 23,000 feet, then hands over the flight to another controller at the center who handles flights above that height. The airplane reaches cruising altitude of 33,000 feet about 100 miles east of Chicago.

The next handoff takes place as Chicago Center passes responsibility to the en-route Cleveland Center in Oberlin, Ohio. One controller tracks the airplane and transfers responsibility to a colleague as the flight passes from one sector to another.

Cleveland Center instructs the pilot to begin descent procedures as aircraft is over western Pennsylvania. The next handoff, to en-route New York Center in Ronkonkoma, N.Y., takes place as the plane is about 75 miles east of La Guardia Airport, New York City.

The plane continues its descent and New York Center hands off responsibility for the flight to the local New York approach-control facility at Garden City, N.Y., where a controller lines up the plane for its final approach to La Guardia Airport.

About 6 miles from the runway, responsibility passes to the tower at La Guardia, where a controller monitors the aircraft's instrument landing. The last handoff of the flight is made from tower to ground control, which directs the plane to its assigned gate.

SOURCE: Newsweek

flown, and demands for air traffic services. They can be grouped in three categories—commercial, GA, and military—with GA exhibiting the greatest diversity. Table 2 is a summary of the U.S. pilot population in 1980 according to the type of license held and the percentage with instrument ratings, i.e., those qualified to use the airspace under IFR. The table shows that about 42 percent of all pilots are now IFR qualified; 10 years ago the percentage was about 30 percent. Almost all of this growth has occurred in the private (GA) category.

Table 3, which is a breakdown of aviation activity according to type of aircraft and hours

Table 2.—U.S. Pilot Population, 1980

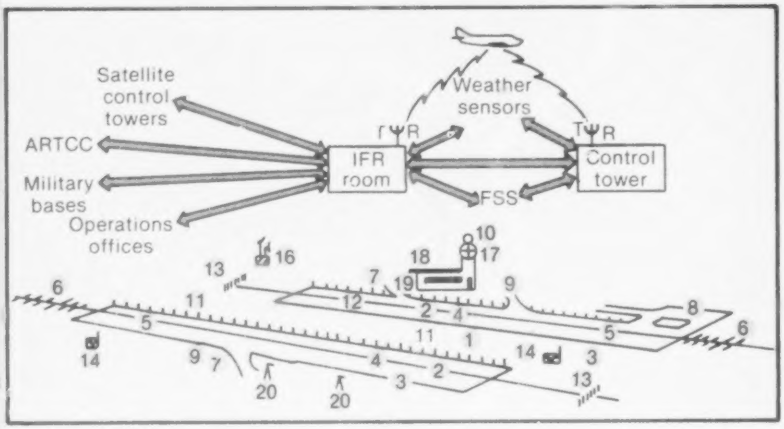
Pilot group	Number	Instrument rated	Percent
Private (GA):			
Student	199,833	0	0
Private license	357,479	39,347	11
Commercial:			
Commercial[a]	183,422	147,741	81
Airline transport license[b]	69,569	69,569	100
Total (excluding students)	610,490	256,547	42

[a] A commercial license allows the holder to work as a pilot and operate on aircraft providing passenger service for hire.
[b] A more advanced rating required of pilots for air carrier airlines.

SOURCE: *FAA Statistical Handbook of Aviation, 1980*

Figure 8.—ATC Facilities and Equipment at a Typical Large Airport

1 Paved runways and taxiways
2 Runway marking
3 Hi-intensity runway lights
4 Centerline lights
5 Touchdown zone lights
6 Hi-intensity approach lights
7 Hi-speed exit taxiways
8 Run-up aprons
9 Taxi guidance indicators
10 Airport surface detection equipment
11 Distance-to-go indicators
12 Visual approach slope indicator
13 Localizer and DME
14 Glide slope
15 Runway grooving
16 ASR and radar beacon
17 Control tower and IFR room
18 Weather services
19 Flight service station and automatic terminal information service (not at all airports)
20 Runway visual range



SOURCE: Federal Aviation Administration

Table 3.—Summary of Aviation Activity, 1980

User group	Number of aircraft	Percent IFR-equipped[a]	Estimated hours flown (millions) Total	IFR[a]	Percent IFR[a]
Commercial air carrier:					
Piston	595	100	0.48	0.48	100
Turboprop	682	100	1.11	1.11	100
Turbojet	2,526	100	6.63	6.63	100
Rotorcraft	2	100	<.01	<.01	100
Total	3,805	100	8.22	8.22[b]	100
General aviation:					
Piston (single-engine)	168,435	34	28.34	2.83	10
Piston (multiengine)	24,578	91	6.41	2.82	44
Turboprop	4,090	99	2.24	1.66	74
Turbojet	2,992	100	1.33	1.22	92
Rotorcraft	6,001	2	2.34	<.01	0
Total	206,096	42	40.66	8.53	21
Military (all types)	18,969	N.A.	5.26	N.A.	N.A.

[a] Estimates based on 1979 survey of general aviation aircraft.

[b] Includes 7.00 million hours for air carriers (all classes); 0.09 million hours for air taxi; 0.99 million hours for commuters; and 0.14 million hours for air cargo.

SOURCES: *FAA Statistical Handbook of Aviation, 1980; General Aviation Activity and Avionics Survey, 1979*, FAA-MS-B1-1, January 1981.

flown, indicates the relative airspace use and demand for IFR services among user categories. Commercial air carrier aircraft (including commuters and air taxis) make up less than 2 percent of the civil aviation fleet, but they account for about 17 percent of hours flown and almost half of the total IFR hours flown in civil aviation. As a class, general aviation aircraft (98 percent of the civil fleet) fly only about 1 hour in 5 under IFR, but this figure is deceptive. Turboprop and turbojet GA aircraft (those with performance characteristics and usage most like air carrier aircraft) are virtually all IFR-equipped and log a very high percentage of their flight hours under

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IFR. The growing numbers and increasing tendency of these more sophisticated GA aircraft to operate under IFR has caused the general increase in ATC system workload over the past 10 years. At present, GA aircraft account for 51 percent of all IFR flight hours, 30 percent of IFR aircraft handled by ARTCCs and 45 percent of instrument approaches at FAA control facilities.

Commercial air carriers are the most homogeneous category of airspace users, although there are some differences between trunkline operators and commuter or air taxi operators in terms of demand for ATC services. Certificated route air carriers follow established schedules and operate in and out of larger and better equipped airports. They have large, high-performance aircraft that operate at altitudes above 18,000 feet en route, where they have only minimal contact with aircraft not under the positive control of the ATC system. In terminal areas, however, they share the airspace and facilities with all types of traffic and must compete for airport access with other users. Airline pilots are highly proficient and thoroughly familiar with the rules and procedures under which they must operate. All air carrier flights are conducted under IFR, regardless of visibility, in order to avail themselves of the full range of services, especially separation assurance.

Commuter airlines also follow established schedules and are crewed by professional pilots. However, they characteristically operate smaller and lower performance aircraft in airspace that must often be shared with GA aircraft, including those operating under VFR. As commuter operations have grown in volume, they have created extra demands on the airport and ATC systems. At one end of their flight they use hub airports along with other commercial carriers and so may contribute to the growing congestion at major air traffic nodes. Their aircraft are IFR-equipped and can operate under IFR plans like other scheduled air carriers, but this capability cannot be used to full advantage unless the airport at the other end of the flight, typically a small community airport, is also capable of IFR operation. Thus, the growth of commuter air service creates pressure on FAA to install instrument landing aids and control facilities towers at more smaller airports.

GA aircraft include virtually all types, ranging from jet aircraft like those used by scheduled air carriers to small single-engine planes that are used only for recreation. Most are small, low-performance aircraft that operate only at low altitudes under VFR, and many use only GA airports and never come into contact with the en route and terminal control facilities of the ATC system. However, there is increasing use of more sophisticated, IFR-equipped aircraft by businesses and corporations, many of whom operate their fleets in a way that approximates that of small airlines. By using larger aircraft and equipping them with the latest avionics, the business portion of the GA fleet creates demands for ATC services that are indistinguishable from commercial airspace users.

It is the disparate nature of GA that makes it increasingly difficult to accommodate this class of users in NAS. The tendency of GA aircraft owners at the upper end of the spectrum to upgrade the performance and avionic equipment of their aircraft increases the demand for IFR services and for terminal airspace at major airports. In response, FAA finds it necessary to increase the extent of controlled airspace and to improve ATC facilities at major airports. These actions, however, tend to crowd out other types of GA, typically VFR users who would prefer not to participate in the IFR system but are forced to do so or forego access to high-density terminal areas. The safety of mixed IFR-VFR traffic is the major concern, but in imposing measures to separate and control this traffic, the ATC system creates more restrictions on airspace use and raises the level of aircraft equippage and pilot qualification necessary for access to the airspace.

Military operations can be placed in two broad categories. Many operations are similar to GA, but others involve high-performance aircraft operating in airspace where they are subject to control by the ATC system. From an operational point of view, military flight activities comprise a subsystem that must be fully integrated within NAS; but military aviation has unique requirements that must also be met, and these requirements sometimes conflict with civil aviation uses. Training areas and low-level routes that are used for training by military aircraft are set aside and clearly indicated on the standard navigation charts. The military services would like to have ranges located near their bases in order to cut down transit time and maximize the time aircrews spend in operational exercises. Civilian users, on the other hand, are forced to detour around these areas at considerable expense in both time and fuel. FAA is charged with coordinating the development of ATC systems and services with the armed forces, so that a maximum degree of compatibility between the civil and military aviation can be achieved.

Chapter 4

AVIATION GROWTH SCENARIOS

Photo credit: Federal Aviation Administration

A busy airport terminal

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Chapter 4

AVIATION GROWTH SCENARIOS

INTRODUCTION

There is a general consensus that domestic aviation activity will increase over the next 10 to 20 years, and with it the demands placed on the Nation's airports and air traffic control (ATC) system. There is far less agreement, however, about how much growth there will be, how it will be distributed, and how it will affect the future characteristics of the National Airspace System (NAS). As a result, there is uncertainty about where system improvements will be needed, and how soon.

Federal Aviation Administration (FAA) plans for the modernization and expansion of the NAS are predicated on the continued rapid growth of air traffic and ATC workloads. Preliminary figures for the most recent FAA "Aviation Forecasts" indicate that the number of aircraft using the system will double by 2000 and that, between 1981 and 1993, total operations will increase by 56 percent at en route ATC centers, by 60 percent at FAA-towered airports, and by 88 percent at flight service stations.

Accommodating this anticipated demand growth has been a primary justification for proposed investments in system improvements, but FAA's forecasts have consistently proven to be too high in the past. In part, this is due to the way in which they are made: FAA makes its forecasts on the assumption that present trends will continue, that there will be no constraints on growth, and that proposed improvements will in fact be made.

Comparison with other aviation forecasts is difficult, since only FAA projects ATC workloads, but it is of interest that some recent forecasts of other measures of demand have been higher than FAA's. In all such projections, however, there is considerable uncertainty about a number of factors that might affect future growth and system requirements, such as U.S. economic growth, fuel prices and availability, airline profitability, new technology, and the possibility of significantly higher aviation user fees. Industry maturity may lead to a leveling-off of airline operations, and changes in route structure may lead to a more even distribution of these operations throughout the system. Even greater uncertainty surrounds the effects of airline deregulation and the long-term impacts of the Professional Air Traffic Controllers (PATCO) walkout.

As a result of these uncertainties, there are valid questions about the accuracy and usefulness of any projection of aviation activity over 10 or 20 years. At present, no individual projection—including FAA's—should be considered more than a broad estimate. Collectively, such projections indicate a likely range of possible futures for NAS and its ATC requirements; but because they are based on similar assumptions and similar forecasting procedures, they may also be subject to similar errors.

This chapter examines and compares a number of projections, but its main focus is on the procedures and assumptions underlying the aviation forecasts on which FAA will base its 1982 system plan. The purpose of this examination is to provide some sense of the range of possible future demand for aviation facilities and services, in order to assist Congress in making its decisions about long-lived investments in both airports and ATC equipment.

FAA AVIATION FORECASTS

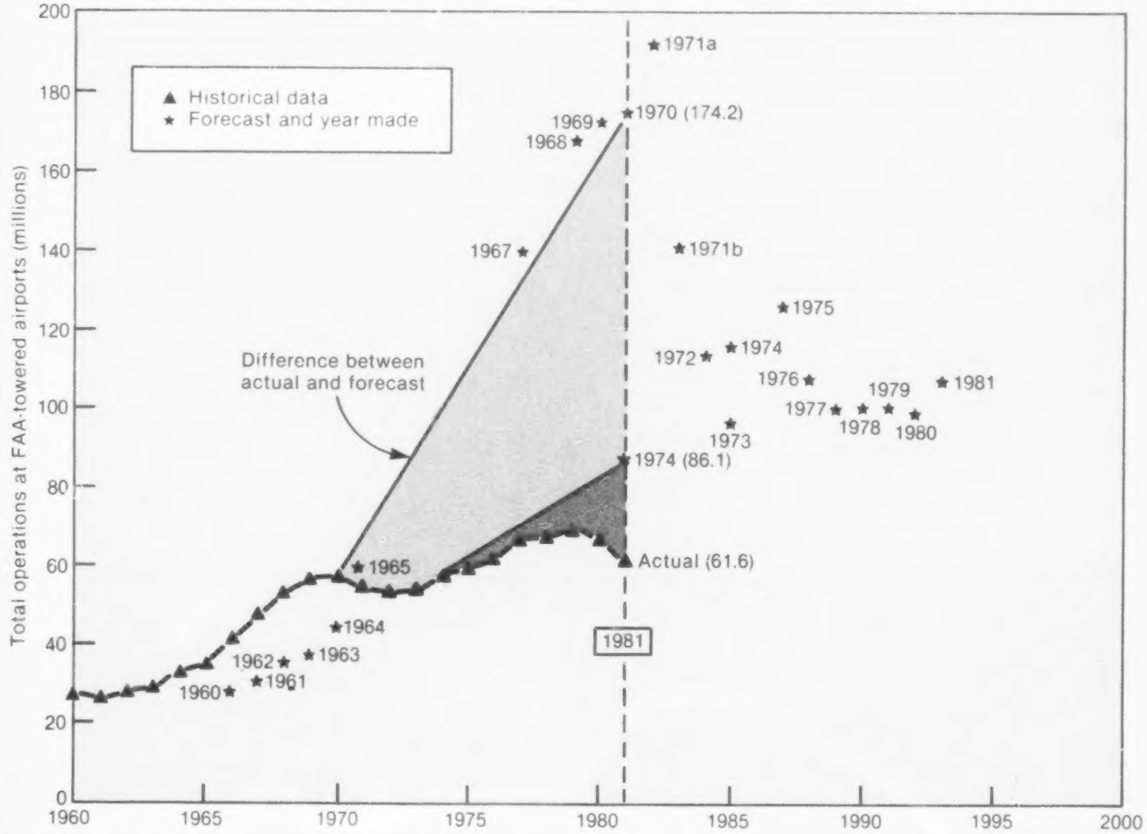
FAA is the most continuous, comprehensive, and detailed source of aviation projections. Its "Aviation Forecasts" are made annually by the Office of Aviation Policy and Plans (OAPP) in support of current operations and as a basis for long-range planning. Many other organizations also use FAA's forecasts as the basis for their own long-range planning activities.

However, FAA has a poor forecasting record: over the past 15 years its predictions have consistently been too high, often by 50 percent or more. Figures 9, 10, and 11 compare past forecasts with actual levels of operations at FAA towers, en route centers, and flight service stations. They show that the workloads originally forecast for fiscal year 1981 were between 50 and 180 percent higher than what actually occurred; in more recent forecasts this level of demand on the ATC system is not expected until the 1990's or later.

Several unforeseeable events combined to cause these errors, including the 1973 oil embargo, sharp increases in fuel prices, rising inflation and interest rates, and airline deregulation. These factors and other pertinent changes in historical trends are now reflected in FAA forecasts, but current expectations may once again be betrayed by unanticipated developments in the future. If key assumptions are overly optimistic, the resulting projections will once again be too high.

Three sets of FAA forecasts were compared in detail for this review: those of September 1978, which predate the Airline Deregulation Act, and those of 1979 and 1980. The year-by-year forecasts for 1982-93, due in October 1981, were "sent to the shredders instead of the printers" (in the words of the Director of OAPP) because the

Figure 9.—FAA Tower Workload, Actual and Forecast, 1960-93



Source: Office of Technology Assessment, from Federal Aviation Administration data.

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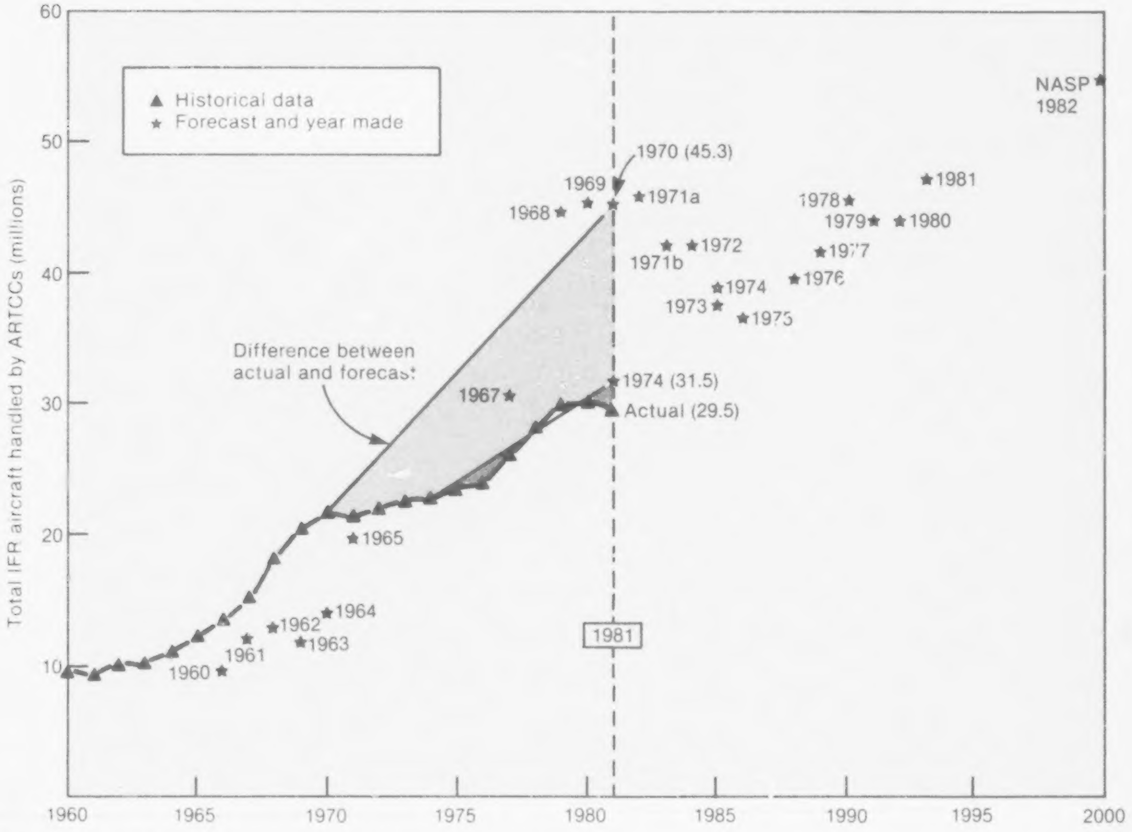
Figure 10.—FAA En Route Workload, Actual and Forecast, 1960-2000



Source: Office of Technology Assessment, from Federal Aviation Administration data.

uncertain impacts of the PATCO walkout had invalidated the short-term projections. Preliminary long-term figures only are used in the following discussion and accompanying graphics, but these projections are somewhat higher than those of 1980 despite a decline in overall activity since 1979. Forecasting procedures, assumptions, and scenario specifications are based on the last published forecast, that of September 1980.

Baseline Scenarios: Procedures and Assumptions

As described in the 1980 "Aviation Forecasts," FAA predictions are based on a combination of econometric modeling, trend extrapolation, and expert judgment. Forecasts of key economic indicators are prepared by Wharton Econometric Forecasting Associates, Inc., using their long-term industry and economic forecasting model. In the withdrawn 1981 forecasts, however, the baseline scenario is based on economic projections supplied by the Office of Management and Budget (OMB) rather than the Wharton model. Aviation activity levels and ATC workloads are derived from these economic indicators by means of aviation submodels designed and run by FAA itself.

The baseline (or most probable) projections are based on the general assumption of unconstrained growth—that past trends will continue and that there will be no change in the relationships between economic activity and aviation variables. Specific assumptions about the various user groups include the following:

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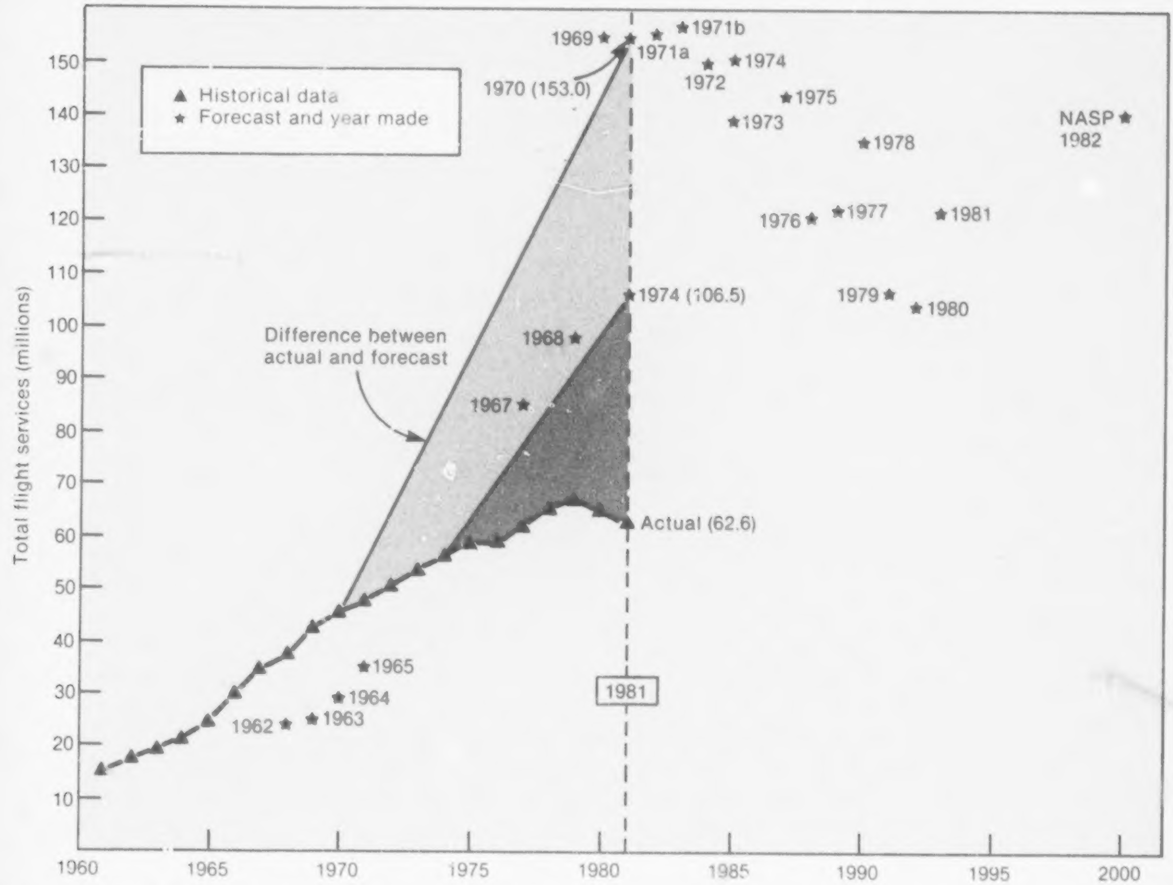
Figure 11.—FAA Flight Service Workload, Actual and Forecast, 1960-2000



Source: Office of Technology Assessment, from Federal Aviation Administration data

- *Federal policy*—no change in Government policy toward the aviation industry (i.e., airline deregulation goes forward, existing noise and pollution standards are implemented, but no new environmental or policy constraints—such as higher user fees—are imposed).
- *General aviation*—continued rapid growth of business and commercial GA (i.e., larger turboprops and jets used as corporate aircraft or air taxis) and continued availability of aviation fuel, although prices rise more rapidly than the consumer price index.
- *Air carriers*—additional mergers, resulting in route optimization and more efficient fleet utilization, and continued replacement of older equipment with larger, quieter, more fuel-efficient aircraft.
- *Commuter carriers*—a decrease in the number of carriers as competition leads to mergers, no loss of competitiveness with the personal automobile, increases in average aircraft size and stage length, and a relatively stable, mature industry after 1984.
- *FAA workloads*—increases in the number of FAA-towered airports and terminal control areas, which will tend to increase the number of IFR operations and flight plan filings, and greater utilization of flight services due to increased convenience and improved services.

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Photo credit: Business and Commercial Aviation Magazine

Business and commercial aviation—a growing sector

Alternative Scenarios

Because of the uncertainties involved in trying to predict the future, FAA forecasts include not only a baseline scenario (the most likely foreseeable outcome) but also alternative scenarios that reflect what might happen if there were major changes in the driving economic, societal, or political factors. Higher and lower economic projections from the Wharton model are run through FAA aviation submodels, and the formal techniques of trend-impact analysis and cross-impact analysis are used to determine the further effects of other events or changes.

Because FAA varies several factors at once, however, it is difficult to assess the sensitivity of the projections to changes in any specific variable. In some cases, moreover, the scenario specifications are so extreme that they undermine the credibility of the resulting projections. Finally, the resulting range of possible outcomes over an 12-year projection is so wide that the alternative scenarios may be of little value for long-range planning purposes. In the 1980 forecasts, for example, the alternative projections of FAA workloads in 1993 were as much as 40 percent higher or 25 percent lower than the baseline. This "range of uncertainty" has increased in recent forecasts (see below).

In 1978 and 1979 there were two alternatives, "high prosperity/slow growth" and "rapid growth/stagflation," respectively. In 1980 there were three alternatives, with the following scenario specifications:

- *"Economic expansion"*—rapid economic growth accompanied by a resurgence of the work ethic, attempts to reestablish U.S. military and economic preeminence in the world, easing of Federal environmental restrictions and market intervention, "tremendous increases" in user fees (especially GA) for airports and ATC services as Federal subsidy of system costs is eliminated, but strong growth in corporate and personal flying due to continued business dispersal and mobile lifestyles.
- *"Energy conservation"*—aviation becomes a "special target" of Federal efforts to achieve energy independence through regulation and taxation, U.S. lifestyle shifts toward that of "a more slow-paced culture," increasingly stringent environmental standards and the closing of some metropolitan airports, reestablishment of Federal control over airline routes and fares, and severe constraints on GA (including higher user fees, fuel rationing, and banning from hub airports).
- *"Stagflation"*—prolonged worldwide recession, strong Federal intervention through nationalization and reorganization of aviation and other industries, severe rationing

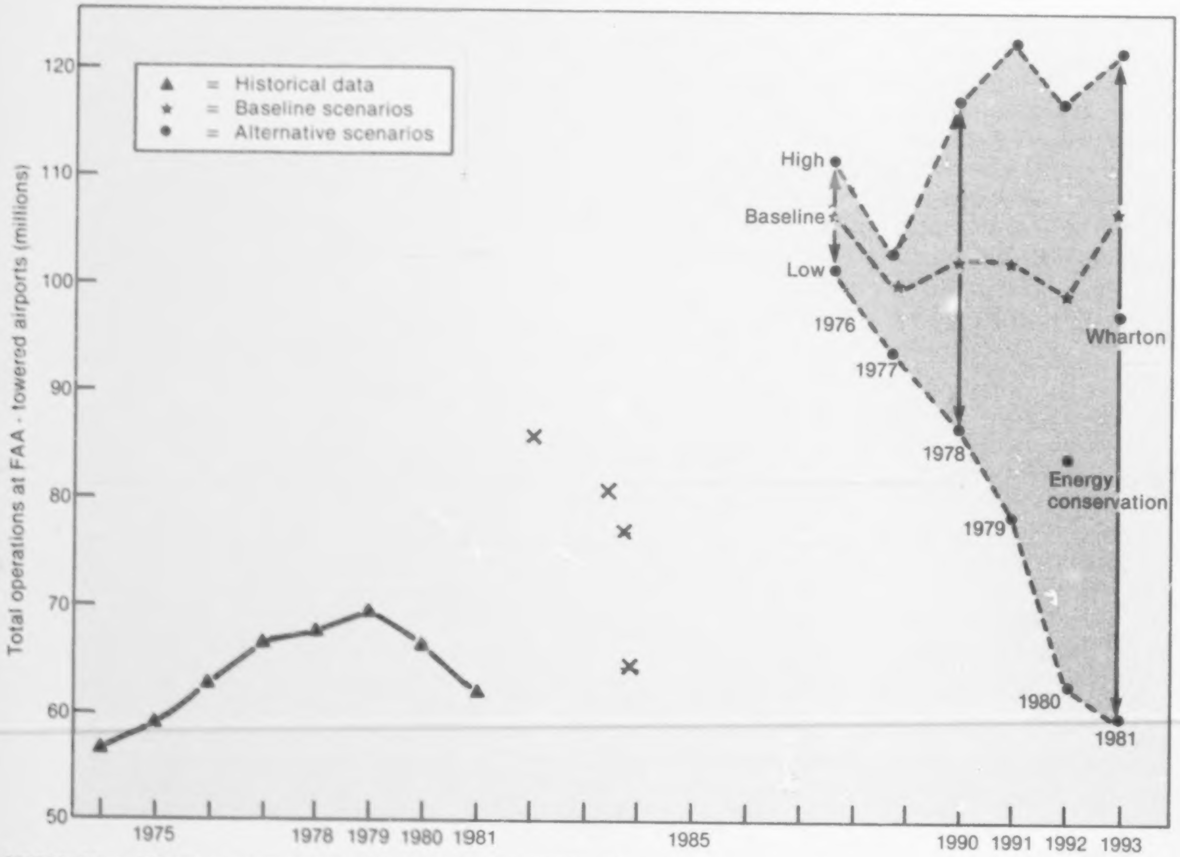
and high prices to encourage energy conservation, increased defense spending and welfare costs, Federal aid keeps major hubs open but many GA airports close and air service to small communities deteriorates, and both business and government make more use of teleconferencing and other substitutes for personal travel.

Preliminary projections for the 1981 "Aviation Forecasts" also include three alternative scenarios: "economic expansion," "Wharton Econometric Model," "stagflation." The middle scenario reflects the baseline Wharton economic indicators and would have been called the "baseline" scenario in past years; the 1981 baseline, however, is based on OMB's economic projections, which are closer to those of 1980 "economic expansion" scenario (3.6 and 3.9 percent average real GNP growth per year, respectively). "Energy conservation" was dropped; the specifications for the other scenarios remain the same as for 1980.

FAA projections of ATC workloads from recent "Aviation Forecasts" are presented in figures 12 through 15. Several features of these projections are worth noting:

- the spread between high and low projections has increased dramatically, suggesting greater uncertainty about future trends;
- the overall range of the projections is lower, suggesting less confidence about the probability of rapid growth;

Figure 12.—Tower Operations, Actual and Forecast, 1974-93



SOURCE: Office of Technology Assessment, from Federal Aviation Administration data.

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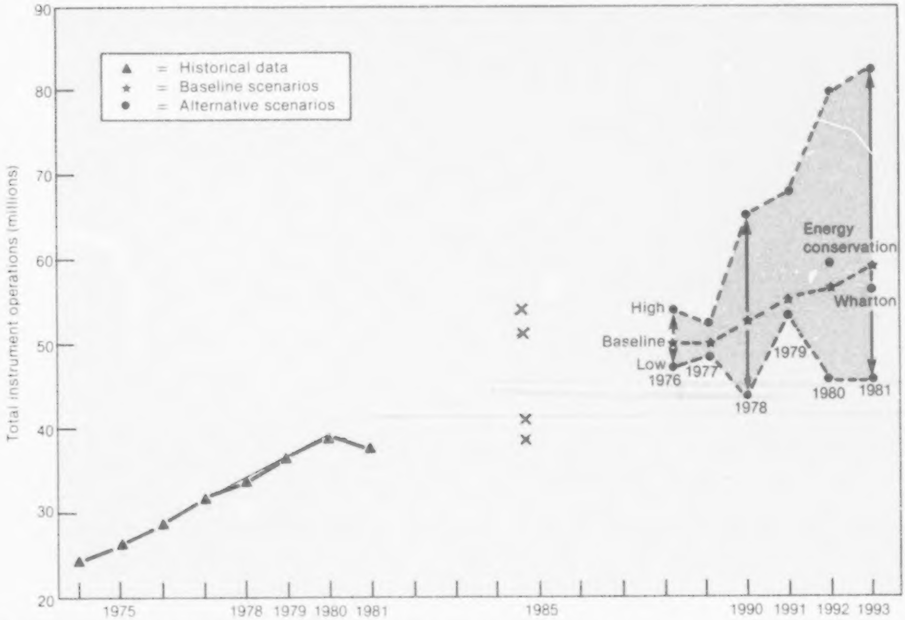
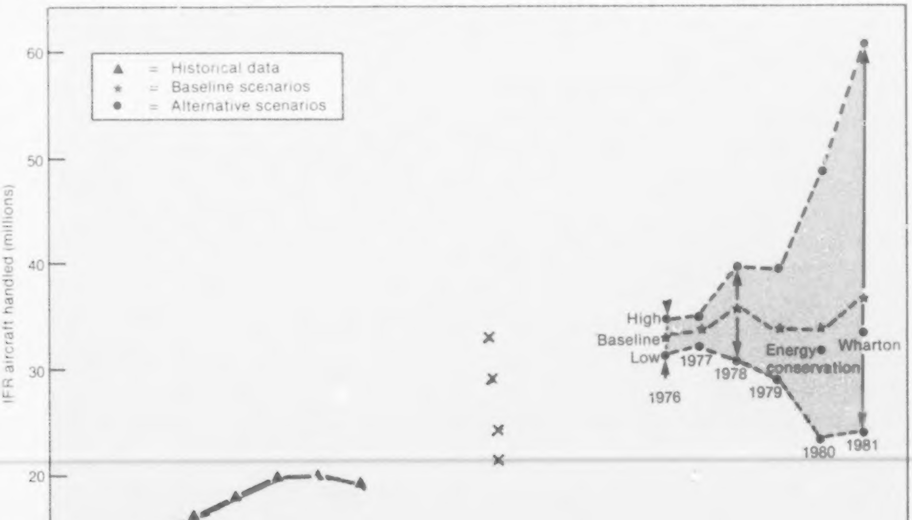
Figure 13.—Instrument Operations, Actual and Forecast, 1974-93



SOURCE: Office of Technology Assessment, from Federal Aviation Administration data.

Figure 14.—IFR Aircraft Handled by En Route Centers, Actual and Forecast, 1974-93



SOURCE: Office of Technology Assessment, from Federal Aviation Administration data.

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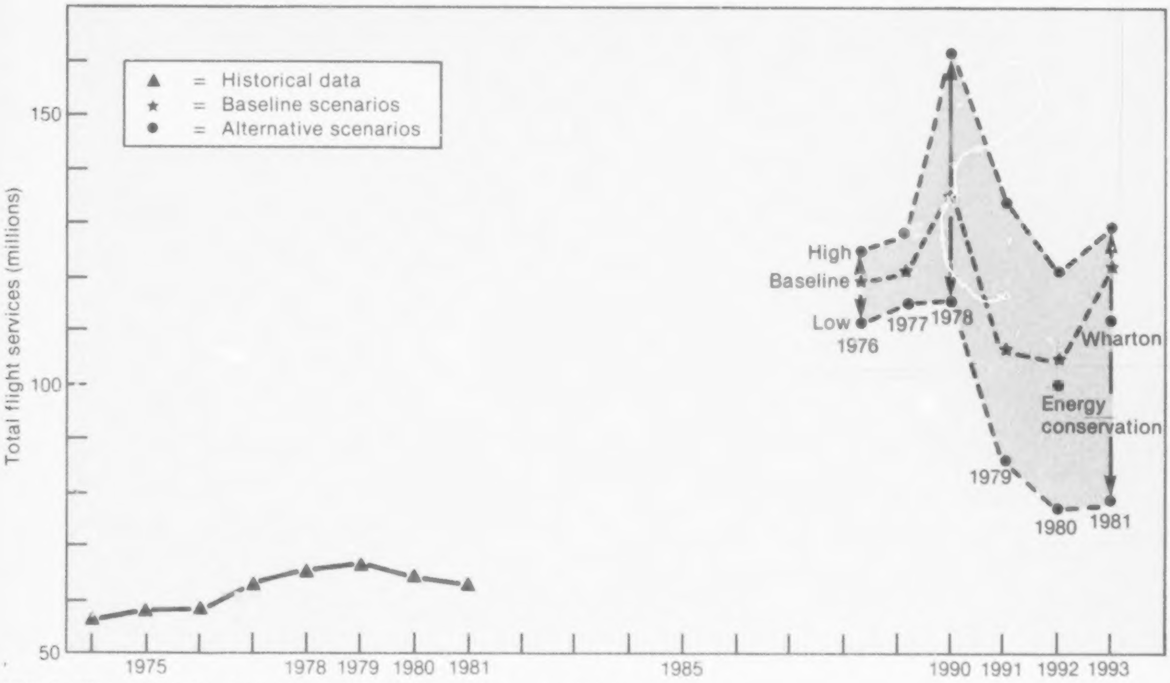
Figure 15.—Total Flight Service Station Activities, Actual and Forecast, 1974-93



SOURCE: Office of Technology Assessment, from Federal Aviation Administration data.

- the baseline projections, on which FAA bases its system plans, have nevertheless moved from the middle of the overall range toward the upper end; and
- the baseline projections are higher in 1981 than in 1980, despite changes in the historical data that would seemingly have caused them to be lower.

The reason for the growing uncertainty in recent "Aviation Forecasts" is not immediately clear. However, in combination with FAA's poor forecasting record in the past (see figs. 9, 10, and 11), it raises questions about the usefulness of FAA forecasts as a guide to decisions about long-term investments in system improvements and expansion.

OTHER AVIATION FORECASTS

Long-range forecasts of aviation activity are also made by a number of organizations other than FAA, including airlines, aerospace manufacturers, investment firms, and private consultants. The scope and emphasis of these forecasts differ according to the purposes and interests of those who make them; understandably, only FAA projects FAA workloads. Nevertheless, they follow the same general approach and employ the same general techniques of analysis and projection. In some cases, however, there are significant differences in their assumptions about the specific variables, trends, or events relevant to the future growth of domestic aviation.

OTA reviewed several forecasts about which the available documentation was sufficiently detailed to permit comparison with FAA projections:

- *Boeing Commercial Aircraft Co.*—These forecasts aim primarily at identifying the

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world market for aircraft in the commercial fleet, rather than the level or patterns of airline operations. Two sets of projections were reviewed: "Dimensions of Airline Growth" (March 1980) and "Current Market Outlook" (November 1981); both are based on economic projections from Case Econometrics.

- *Transportation Research Board (TRB).*—This is not a regularly published forecast but rather a result of the ongoing activities of the Aviation Forecasting Committee of TRB, which is part of the National Research Council of the National Academy of Sciences. Published in August 1981 as "Assumptions and Issues Influencing the Future Growth of the Aviation Industry," the forecast represents the consensus of forecasting workshop participants representing most segments of the aviation community.
- *Office of Technology Assessment (OTA).*—These projections were commissioned by OTA to provide different kinds of information than was provided by the other major forecasts. In particular, its structure and assumptions are designed to project the *distribution* as well as the *volume* of future aviation activity, in order to determine its impact on airport congestion and ATC capacity (see below). It is thus a "conditional" forecast, since its different assumptions require a change in current traffic patterns and industry structure.
- *Other Aviation Forecasts.*—Recent updates to the 1975 Air Transport Association (ATA) forecast became available during the course of this study, as did the most recent edition of Lockheed-California Co.'s regularly published "World Air Traffic Forecast." The ATA forecast focuses on the financial performance and capital needs of the airline industry, while the Lockheed report emphasizes international rather than domestic traffic. However, neither report presents its forecast on a level of detail consistent with the above forecasts, and as a result they are given only cursory treatment in the discussion that follows. The judgments and informal forecasts of a number of other sources have also been considered in OTA's analysis.

Forecast Structures and Assumptions

Table 4 presents the specific features and results of the six forecasts that have been studied in detail. In each case, the forecast begins by assuming the macroeconomic indicators that are believed to be the driving force behind air traffic growth, and then uses these variables to generate the growth rates and absolute levels of aviation activity at the end of the forecast period. Although disposable personal income (DPI) appears to be the most important driving variable in most of the forecasts, the direct link between macroeconomic forecasts and traffic forecasts is seldom explictly given.

On the basis of their economic projections, the forecasts then derive growth rates and actual levels of commercial air traffic in terms of revenue passenger miles (RPMs). FAA and OTA forecasts are the only ones that include explicit reference to GA operations; giver the increasing importance of GA activity, its absence is a major shortcoming in the other forecasts. Similarly, only FAA's "Aviation Forecasts" proceed from traffic levels to FAA workloads; lacking this further analysis, the other major forecasts (including OTA's) are useful only for purposes of comparison in evaluating the traffic growth and aircraft fleet mixes that the ATC system would need to accommodate.

All of the projections include alternative scenarios that reflect different assumptions about economic growth, typically referred to as low, medium, and high. The most recent FAA forecasts contain four scenarios, but only the baseline scenario is described in detail. Beyond these scenario specifications, none of the forecasts postulates specific events that might affect traffic growth of system evolution; all of them assume—explicitly or implicitly—that no "major catastrophe" will occur. (The PATCO strike and subsequent traffic restrictions may not constitute such a catastrophe, but they do affect the short-term prospects of growth and may affect long-term patterns. This has created sufficient

Table 4.—Comparison of Selected Economic Assumptions and Aviation Growth Predictions

<table>
<tr><th rowspan="2">Forecast</th><th rowspan="2"></th><th colspan="2">Real GNP[a] growth (percent/year)</th><th colspan="2">Real DPI[b] growth (percent/year)</th><th colspan="2">RPM[c] growth (percent/year)</th><th rowspan="2">RPMs 1991 (millions)</th><th rowspan="2">Load factor 1991 (percent)</th></tr>
<tr><th>1979-86</th><th>1986-91</th><th>1979-86</th><th>1986-91</th><th>1979-86</th><th>1986-91</th></tr>
<tr><td>FAA 1978</td><td>high</td><td>4.4</td><td>4.6</td><td>4.4</td><td>4.4</td><td>6.8</td><td>4.6</td><td>406</td><td>60.0</td></tr>
<tr><td></td><td>med</td><td>3.3</td><td>3.2</td><td>3.7</td><td>3.1</td><td>5.4</td><td>4.5</td><td>369</td><td>60.0</td></tr>
<tr><td></td><td>low</td><td>2.8</td><td>2.5</td><td>2.9</td><td>2.2</td><td>2.8</td><td>4.4</td><td>308</td><td>60.0</td></tr>
<tr><td>FAA 1979</td><td>high</td><td>4.0</td><td>4.9</td><td>3.9</td><td>5.7</td><td>6.0</td><td>6.7</td><td>426</td><td>62.0</td></tr>
<tr><td></td><td>med</td><td>2.8</td><td>2.8</td><td>2.5</td><td>2.8</td><td>5.5</td><td>4.2</td><td>365</td><td>62.0</td></tr>
<tr><td></td><td>low</td><td>2.5</td><td>2.1</td><td>1.8</td><td>1.6</td><td>4.4</td><td>4.0</td><td>336</td><td>62.0</td></tr>
<tr><td>FAA 1980</td><td>high</td><td colspan="2">3.7</td><td colspan="2">3.8</td><td colspan="2">5.8</td><td>405</td><td>63.3</td></tr>
<tr><td></td><td>med</td><td>2.3</td><td>2.9</td><td>2.3</td><td>3.0</td><td>4.8</td><td>3.7</td><td>341</td><td>63.3</td></tr>
<tr><td></td><td>alt</td><td colspan="2">2.9</td><td colspan="2">2.8</td><td colspan="2">4.3</td><td>342</td><td>63.3</td></tr>
<tr><td></td><td>low</td><td colspan="2">2.1</td><td colspan="2">1.9</td><td colspan="2">3.6</td><td>314</td><td>63.3</td></tr>
<tr><td>FAA 1981</td><td>high</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td></td><td>OMB</td><td>3.6</td><td></td><td>3.3</td><td></td><td>4.9</td><td></td><td>346</td><td>N/A</td></tr>
<tr><td></td><td>med</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td></td><td>low</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Boeing 1980</td><td>high</td><td>3.0</td><td>3.1</td><td colspan="2">N/A</td><td>6.5</td><td>5.5</td><td>434</td><td>66.2</td></tr>
<tr><td></td><td>low</td><td>2.4</td><td>3.0</td><td colspan="2">N/A</td><td>4.6</td><td>3.9</td><td>354</td><td>66.2</td></tr>
<tr><td>Boeing 1981</td><td>high</td><td colspan="2">3.0</td><td colspan="2">N/A</td><td colspan="2">7.3</td><td>358</td><td>N/A</td></tr>
<tr><td></td><td>low</td><td colspan="2">2.6</td><td colspan="2">N/A</td><td colspan="2">4.6</td><td>336</td><td>N/A</td></tr>
<tr><td>TRB 1981</td><td>high</td><td>4.3</td><td>3.5</td><td>4.3</td><td>3.5</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td></td><td>med</td><td>3.2</td><td>2.8</td><td>3.2</td><td>2.8</td><td>7.0</td><td>7.0</td><td>450</td><td>63.0</td></tr>
<tr><td></td><td>low</td><td>2.4</td><td>2.2</td><td>2.4</td><td>2.2</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>OTA 1981</td><td>high</td><td colspan="2">4.3</td><td colspan="2">4.3</td><td colspan="2">7.5</td><td>443</td><td>60.0</td></tr>
<tr><td></td><td>med</td><td colspan="2">3.4</td><td colspan="2">3.4</td><td colspan="2">5.5</td><td>360</td><td>60.0</td></tr>
<tr><td></td><td>low</td><td colspan="2">2.5</td><td colspan="2">2.5</td><td colspan="2">4.1</td><td>311</td><td>60.0</td></tr>
<tr><td>Range of all forecasts</td><td>high</td><td colspan="2">3.0-4.5</td><td colspan="2">3.8-4.6</td><td colspan="2">5.8-7.5</td><td>405-600</td><td></td></tr>
<tr><td></td><td>med</td><td colspan="2">2.7-3.6</td><td colspan="2">2.7-3.4</td><td colspan="2">4.3-7.0</td><td>341-460</td><td>60.0-66.2</td></tr>
<tr><td></td><td>low</td><td colspan="2">2.0-2.8</td><td colspan="2">1.7-2.5</td><td colspan="2">3.6-4.6</td><td>311-450</td><td></td></tr>
</table>

[a] Gross national product.

[b] Disposable personal income.

[c] Revenue passenger miles.

uncertainty that FAA has delayed publication of the 1981 forecasts until the impacts can be assessed.)

Comparison and Critique of Forecasts

All of the major forecasts assume roughly similar economic growth rates. FAA's projections have tended to be lower than the others and had become more so in recent years, although the preliminary figures for the withdrawn 1981 forecast reflect OMB's optimism about future economic growth. Nevertheless, given the range of forecast growth rates, the differences between the individual economic assumptions are probably not significant. In terms of aviation-specific factors, there also seems to be general agreement among the projections about variables such as load factors, aircraft size, and stage length.

Not surprisingly, the resulting growth rates for domestic RPMs are also quite similar. OTA's projections for RPMs tend to be at the upper end of the range for all the forecasts. The 1980 FAA forecasts are slightly but not significantly lower than the others. Despite the more optimistic economic assumptions, the 1981 FAA forecasts (if and when published) will probably be somewhat lower as well. Lockheed's corresponding forecast, a single figure of 307 billion RPMs in 1990, is somewhat lower than any of the forecasts included in table 4.

Only the FAA and OTA-commissioned forecasts break down these RPM figures into projections of air carrier operations by type. FAA's operations forecasts are considerably lower than OTA's, particularly in the 1980 forecast. Where the OTA "low" scenario translates 4.1-percent RPM growth into 1.5-percent annual growth in air carrier operations, the 1980 FAA "baseline" scenario shows 4.3-percent RPM growth but no operations growth, and the FAA "stagflation" scenario translates 3.6-percent RPM growth into a 0.8-percent *decline* in operations. As a result, OTA's forecast range for air carrier operations in 1991 is 12.1 million to 19.6 million, while the FAA's is 9.2 million to 15.5 million. The corresponding projection from the Air Transport Association, reflecting the judgments of its airline members, is for 10.4 million air carrier operations in 1990. The overlap between these projections is sufficiently wide that the differences are probably not significant, particularly when structural differences between the models are considered. However, because the forecasts rely on common assumptions, they produce similar results all of which may be in error for the same reasons.

The TRB Aviation Demand Forecasting Committee's 2-day workshop on FAA aviation forecasts resulted in four principal recommendations, all of which also apply to the other forecasts considered here. In the opinion of the workshop participants, the following features are needed by planners and decisionmakers alike:

- high and low estimates of key assumptions to measure the extent of uncertainty about driving variables, and consequently an increase in the number of alternative scenarios (at present the FAA provides complete results only for its "baseline" scenario);
- a variety of techniques rather than a single technique, in order to produce better forecasts or competing scenarios;
- in particular, less reliance on econometric models and more on expert judgment (especially industry experts), taking account of nonlinear economic relationships and noneconomic factors; and
- forecasts of components rather than aggregates alone—regional and local activity rather than national, for instance, and point-to-point traffic levels rather than only total volumes.

FACTORS AFFECTING TRAFFIC GROWTH

The future growth of aviation activity in the United States will be affected by a number of factors that are not or cannot be anticipated adequately or with certainty in the models used for the forecasts discussed above. In some cases these factors may constitute "levers" through which the rate or pattern of growth might be influenced through appropriate policies or programs. In most cases, however, neither the direction nor the impact of these factors can be accurately foreseen. These factors include but are not limited to those discussed below.

U.S. Economic and Regulatory Policy

The preliminary figures for FAA's 1981 forecasts reflect considerable optimism about the implementation and success of the present administration's economic recovery plan. The growth and structure of the aviation system will be influenced significantly by the speed and strength with which the Nation recovers from the current recession. The growth of aviation will also continue to be influenced by air safety and air traffic regulations, by the way in which ATC system costs are apportioned through user fees and aviation taxes, and by the constraints imposed by present and future noise and environmental regulations. The potential impact of these economic and policy factors is uncertain and subject to future changes.

Deregulation

Airline deregulation has destabilized the industry's price and market structures. Some analysts believe that the transition toward a free marketplace is causing overcompetition, which in turn is undermining major airline profitability and reducing their ability to finance badly needed new equipment. Termination of Section 406 and 419 subsidies in 1985 and 1988 will also affect commuter airline profits and may affect air service to as many as 100 small- and medium-size cities. Some analysts feel that the demise of some carriers may be a natural and indeed desirable result of complete deregulation, since the elimination of financially ailing carriers would relieve the overcapacity that currently hinders healthier competitors. Some analysts predict the bankruptcy of a major carrier by mid-1982, and that by 1990 the industry will probably witness considerable consolidation through mergers, acquisitions, and outright failures. The survivors, however, may be in a far stronger financial and competitive position.

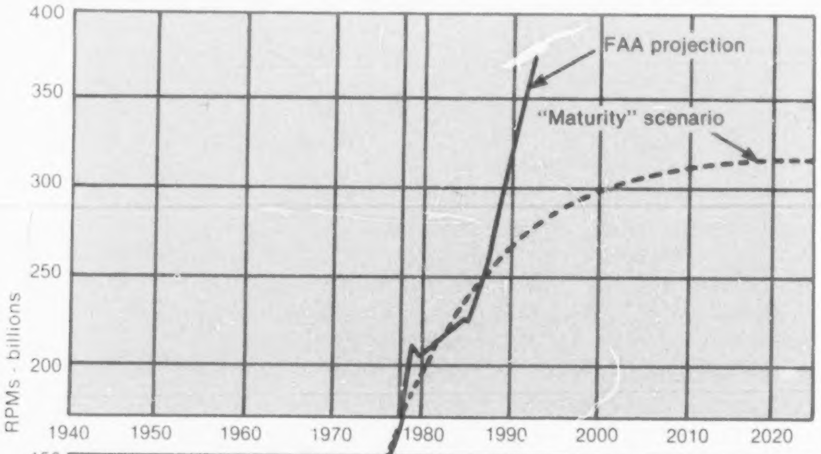
Industry Maturity and Structure

Rolls Royce, a major aerospace manufacturer, has suggested that even if positive steps are taken to reduce costs and increase efficiency, the U.S. airline indsutry has already reached about 60 percent of its mature size (see fig. 16). Others put the figure at closer to 80 percent. If this is so, then major air carrier passenger traffic may begin to level off before the end of the century, and tower operations might actually decline. The continued growth of commuter carriers and GA traffic might nevertheless result in a continued increase in the number of airport and ATC operations beyond 2000, but FAA expects commuters too to become a "stable, mature industry" after 1985 and GA may face growth constraints. It seems likely, in any case, that by 1990 there will be a smaller number of trunk carriers, offering primarily long-haul service; a declining number of specialized carriers, offering low-cost service in major hubs and major markets; and a large number of commuters of various sizes, including some that offer "regional" service.

Fuel and Labor Costs

The greatest uncertainty facing domestic aviation in both the short and the long term is the future price and availability of aviation fuels. This factor is crucial to the continued profitability of the airlines, which depends in a major way on their ability to absorb any differences between the increase in fuel prices and the increase in the CPI. The future course of fuel prices can only be

Figure 16.—Projected U.S. Certificated Air Carrier Growth



SOURCE: Rolls Royce, Inc., *U.S. Airlines Indicators and Projections*, July 1981.

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guessed at, particularly in view of uncertainty about future OPEC policy and the inherent instability of the Middle East. However, the current "oil glut" and price decreases are probably a transient event in the long-term price trend, although it is less certain whether or how rapidly the real price of fuel will rise in the future. No long-term shortage is expected. There are indications, however, that aviation gasoline (used by smaller piston-engined GA aircraft) may be increasingly difficult to obtain. GA activity is particularly sensitive to fuel prices, but rapid increases are more likely to reduce personal GA traffic than business and commercial GA (corporate and air taxi users, who generate greater demand for ATC services).

Labor costs are also a major factor in air carrier profitability, and airlines can be expected to seek long-term wage and benefit concessions from their unions during the 1982 round of contract negotiations. Financing costs may also become an increasingly important factor in the future.

Technology

Considerable optimism remains about the future impact of advanced air transport technology, but such improvements are likely to be introduced more slowly in the future than over the last 20 or 30 years. Recent improvements in airline efficiency and productivity have come through higher utilization and economies of scale (aircraft size and seating density) rather than technology (aircraft speed or fuel efficiency). Several promising new developments appear to be possible in the near future, but there is a considerable amount of aviation technology currently "on the shelf" that is only beginning to appear in the U.S. fleet. Whether the aerospace industry will continue to develop a new generation of advanced-technology aircraft will depend on the potential market, and this in turn depends on the ability of the airlines to generate profits and/or obtain financing. Several manufacturers have announced plans for a new 150-passenger aircraft for the late 1980's; several new commuter aircraft will be available even sooner. Some near-term increases in fleet efficiency could, however, be achieved by retrofitting engines and making other modifications to existing aircraft.

Financing

Reports by various airline and banking sources indicate that the equipment needs of the U.S. airline industry will impose capital requirements of $50 billion to $100 billion by 1990, compared to total capital additions of only $30 billion between 1960 and 1979 (current dollars). This capital requirement would demand an average annual corporate return on investment (ROI) of 13 to 15 percent for the entire decade. Industry ROI averaged 6.4 percent during the 1970's, and only once—in 1978—has it risen as high as 13 percent. There are signs of increasing reluctance on the part of insurance companies and even banks to provide long-term debt, even when secured by the leveraged-lease financing or equipment trust certificates that were used in the 1970's. Deregulation has further increased the risks and uncertainties of airline financing, although a restructuring of the industry through bankruptcies or mergers (see above) might alter this situation in the future. Without a firm market, furthermore, aerospace manufacturers might be less willing to develop and introduce more advanced aircraft in the future.

Substitution for Air Transport

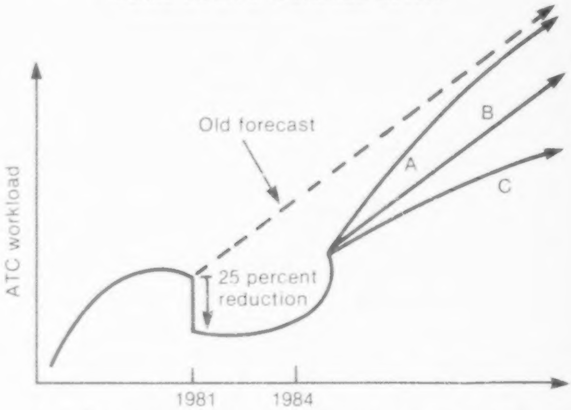
Very little can be said with any certainty about the future impacts of developments in either substitute transportation modes (such as high-speed trains or, with higher speed limits and gas mileage, the personal automobile) or alternatives to travel (such as advanced telecommunication technologies and corporate teleconferencing). Neither is likely to cut into aviation's long-haul markets, although the industry may find it increasingly difficult to compete with the automobile and train in short-haul markets (under 200 or perhaps even 300 miles).

Strike Impacts

Ironically, the PATCO strike has in effect reregulated the industry by imposing traffic restrictions on the 22 busiest hubs and by placing severe constraints on GA traffic. Some observers feel that the strike may actually have helped airline profits by removing overcapacity and enabling major carriers to ground inefficient aircraft, lay off personnel, and reduce other costs. On the other hand, these same restrictions impose constraints on GA traffic and on the expansion of commuter carriers and new entrants.

Strike-related traffic restrictions will probably continue for at least 2 more years, and adjustments made by users during this period may permanently change aviation growth trends and traffic distribution. As a result, there is little certainty about the long-term impact on the level of operations: traffic might rebound rapidly, but previously projected levels might not be reached until later than anticipated, if at all (see fig. 17). In addition, these traffic restrictions (particularly at major hubs) could be extended or reimposed in the future as a means of addressing airport congestion and encouraging redistribution of operations to second-tier hubs (see the following section).

Figure 17.—Possible Long-Term Impacts of PATCO Strike on ATC Workload Levels



A = Built-up demand causes rapid recovery and workload quickly matches projected levels.
B = Steady recovery and projected rate of growth, but workload matches projection later than anticipated.
C = Strike stunts demand growth and ATC workload never achieves projected level.

NOTE: For illustrative purposes only, and not based on specific FAA forecasts.

SOURCE: Office of Technology Assessment.

IMPLICATIONS FOR AIRPORT CONGESTION

Despite the uncertainties involved in forecasting precise rates of growth, there is a general consensus that air traffic and the demand for ATC services will increase in the next 10 to 20 years. There is also a consensus that much of this growth will come from the GA sector rather than the airlines, and within the GA sector from business and commercial aircraft rather than personal flying. There is far less agreement on how this growth will be distributed through the system or how it will affect the problem of airport congestion and delay.

FAA forecasts indicate that continued rapid growth of air traffic, if it occurs along existing patterns at existing airports, will result in severe airside congestion at 46 air carrier airports by 2000. FAA's forecasts have consistently overestimated growth in the past, and a number of factors may constrain growth in the future (see above). Nevertheless, airside capacity could become an increasingly serious problem at more of the Nation's airports by the end of the century unless there are improvements in airport capacity or traffic management (see ch. 6).

An alternative to this prospect, however, is the redistribution of air carrier operations across more of the top 50 airports, in combination with improved facilities at additional GA reliever airports. This alternative is discussed below; specific improvements in ATC technology and airport management that would complement it are examined in chapters 5 and 6. The economic and aviation growth rates on which the following discussion is based are presented in table 5.

Continued Growth and Airport Saturation

The primary measure of aviation activity as it bears on airport and ATC decisions is "opera-

Table 5.—Aviation Growth Assumptions for "Redistribution" Scenarios, Domestic Service, 48 States

	Jets			Propeller aircraft		
1978:						
Revenue passenger miles	200 billion			1.7 billion		
Operations at top 50 commercial airports	7.2 million			1.8 million		
	Low eonomic growth	Average economic growth	High economic growth	Low economic growth	Average economic growth	High economic growth
2000:						
Revenue passenger miles: average annual growth rate ....percent..	4.1	5.5	7.5	4.1	5.4	6.9
Revenue passenger miles: year 2000 ....billions..	450	600	900	~4	~5	~7
Operations: average annual growth rate ....percent..	1.6*	2.2*	3.0*	2.4	1.6*	2.4*
Operations at top 50 commercial airports ....millions..	10*	11.2*	13*	2.9	2.5*	2.9*

*Assuming effects of airport capacity constraints.

NOTE. Real GNP growth rates:

Low	2.5
Average	3.4
High	4.3

tions"—landings and takeoffs, or arrivals and departures (each flight generates two operations). Figure 18 illustrates the 1978 mix of air activity at the top 50 commercial airports, ranked by air carrier operations and aggregated into sets of 5 airports to simplify presentation. Most of the operations at these airports are generated by scheduled passenger flights, but although there are few local operations at the top 15 airports, GA traffic (predominantly corporate aircraft and air taxis) is seldom less than 10 percent of operations.

Figure 18 also shows the estimated airside capacity of these airports, expressed in terms of the "practical annual capacity" (PANCAP) that can be handled safely, as estimated by FAA in 1978. Actual airside capacity is variable, however, changing with weather conditions or aircraft mix; the balance is a delicate one, and at busy hubs even a slight deterioration from optimum conditions can cause long lines of delayed aircraft. PANCAP—the level of operations at which 80 percent of aircraft encounter delays of 4 minutes or longer—thus represents an approximate figure based on assumed average utilization of the existing number and configuration of runways, rather than an absolute or reliable measure of capacity.

Saturation—the level at which delay is chronic—may not occur at a given airport until operations are as much as 100 percent *above* PANCAP, so that small differences between actual operations and PANCAP are not necessarily significant. Large differences, on the other hand, indicate a rising probability of encountering delays at the airport at least part of the time. The discrepancy at most of the top 10 airports in figure 18 represents a significant capacity shortage relative to demand (the desired level of operations), and in most cases this situation has existed since the late 1960's.* It is assumed in the following discussion that when operations are more than 10 percent above PANCAP, the result will be airport saturation and chronic delay.

Figures 19 through 21 show the PANCAP, the 1978 level of operations, and the levels of operations in 2000 projected under three aviation growth scenarios. These projections assume that traffic growth will occur at the same rate across existing airports, irrespective of capacity limita-

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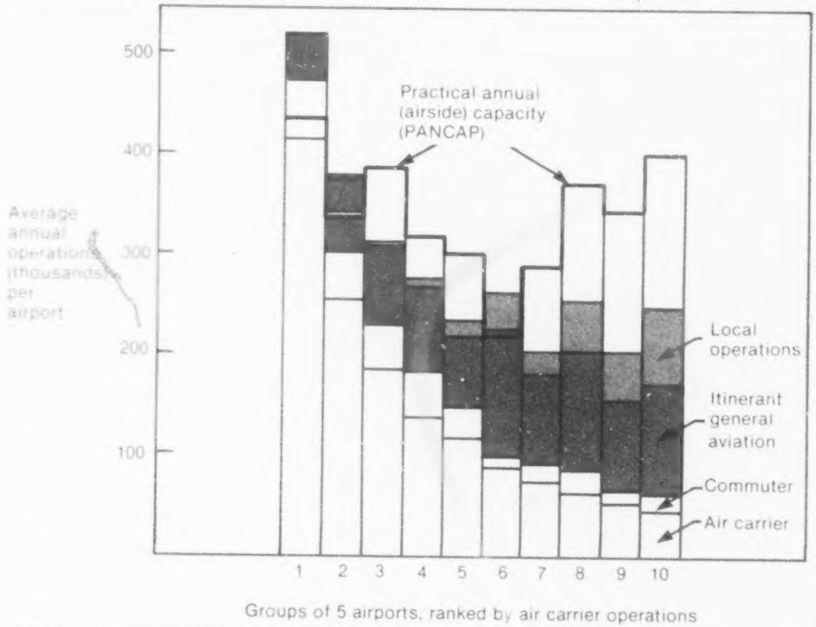
*The discrepancy between PANCAP and actual operations in the sixth airport group (which includes Phoenix, Fort Lauderdale, Orlando, San Diego, and Portland) does not indicate a significant capacity problem. These airports handle a large volume of GA traffic that is discretionary as to time of day and weather conditions, both of which increase actual capacity over a PANCAP figure.

Figure 18.—Activity at Top 50 Commercial Airports, 48 States, 1978

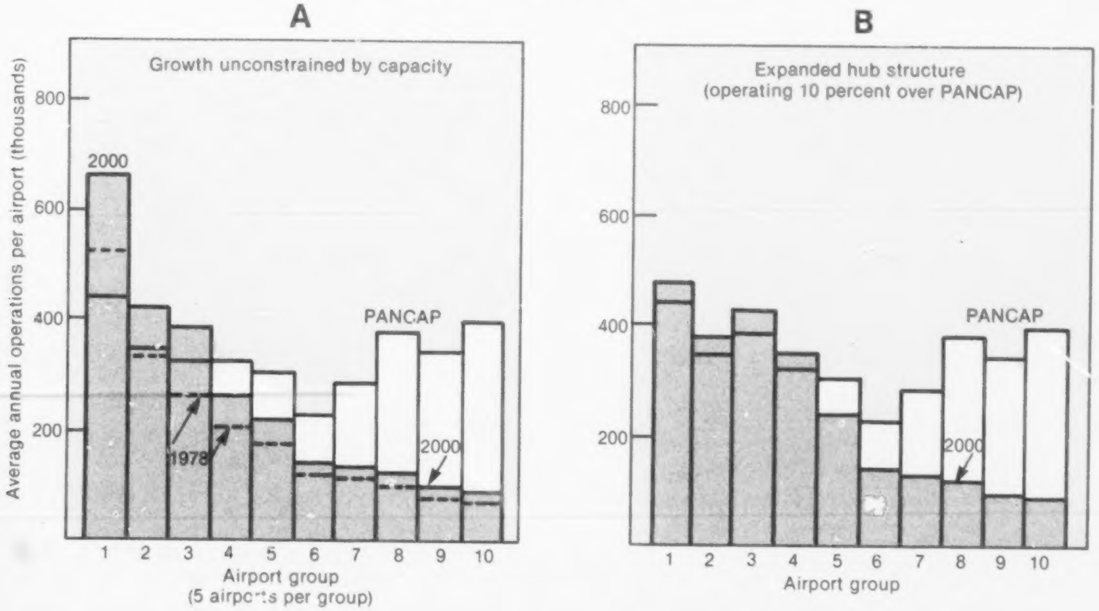


SOURCE: Office of Technology Assessment.

Figure 19.—Airport Airside Capacity Perspective—Low Economic Growth Scenario

(Jets plus propeller service plus 10 percent for general aviation)

(1.3 percent average growth rate in operations)



SOURCE: Office of Technology Assessment.

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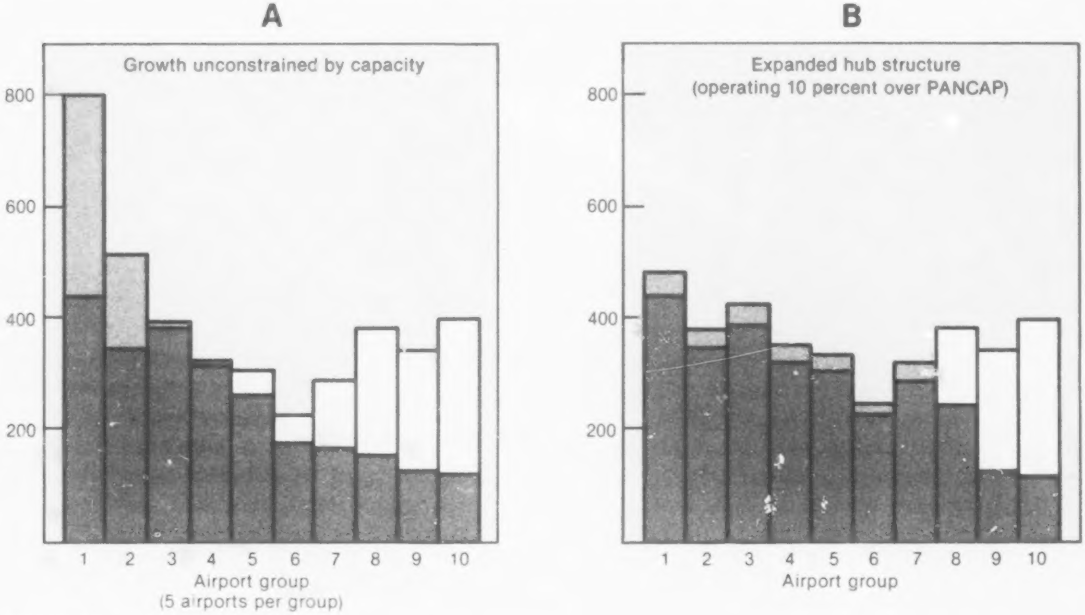
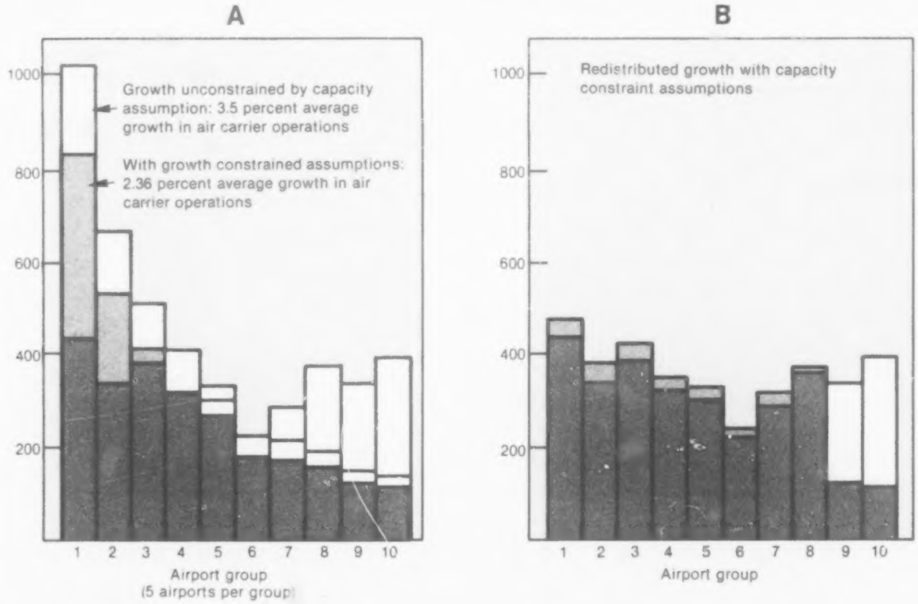
Figure 20.—Airport Airside Capacity Perspective—Average Economic Growth Scenario
(Jets plus propeller service plus 10 percent for general aviation)
(2.3 percent average growth rate in operations)



SOURCE: Office of Technology Assessment.

Figure 21.—Airport Airside Capacity Perspective—High Economic Growth Scenario
(Jets plus propeller service plus 10 percent for general aviation)



SOURCE: Office of Technology Assessment.

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tions. Under conditions of low economic growth, desired operations exceed PANCAP only at the top 10 airports; at the top 5 airports, however, demand will be about 50 percent above PANCAP (fig. 19A). Under conditions of *average economic growth*, desired operations would exceed PANCAP at the top 20 airports, and traffic at the 5 busiest hubs would be almost 200 percent of PANCAP (fig. 20A). Under conditions of *high economic growth*, desired operations would be higher than PANCAP at over 30 airports, and the top 5 hubs would experience almost 250 percent of PANCAP (fig. 21A). To avoid these conditions, the carriers would probably increase aircraft size and drop service points, particularly in short-haul markets, in order to reduce overall operations. This adjustment, also shown in figure 21A, could reduce overall traffic levels by roughly 24 percent, but there would still be serious congestion problems at the top 10 or 15 hubs.

Redistribution of System Operations

In 1978 the level of scheduled commercial operations at the top 50 airports was about 52 percent of their combined PANCAP. However, these operations were heavily concentrated toward the five largest airports (where traffic levels exceeded PANCAP by 20 percent), while considerable excess capacity existed at the other 45 hubs. In addition, over half of the passengers arriving at the five largest hubs did so only to change planes.

OTA examined the effect of redistributing the expected increases in operations to these less crowded airports. In the following discussion it will be assumed that 110 percent of PANCAP—i.e., saturation—represents a desirable level of operations (or an acceptable level of delay) at any given airport. The results, shown on the right side of figures 19 through 21, indicate that the combined existing capacity of the top 50 airports could accommodate substantial increases in commercial operations if they were redistributed.

Low economic growth would result in 20 airports at 110 percent of PANCAP, instead of 5 airports at 150 percent (fig. 19B). *Average economic growth* would result in 38 airports at 110 percent of PANCAP, instead of 10 airports over 150 percent and the top 5 at almost 200 percent (fig. 20B). *High economic growth* would result in traffic levels of 113 percent of PANCAP at all of the top 50 airports even if redistributed, instead of almost 15 airports at 150 percent and the top 5 airports at almost 250 percent; but if airlines respond to capacity constraints by increasing aircraft size and dropping some service points, as well as redistributing operations, the result would be levels of 110 percent of PANCAP at only 38 of the top 50 air carrier airports (fig. 21B).

Such a redistribution would be accomplished primarily by "rehubbing" airline route structures—that is, by moving the interline function (that of providing a transfer point) from congested airports to the "second tier" hubs where excess capacity still exists. There are indications that such changes in the airline network are already taking place. United Airlines, for instance, has been shifting some of its operations from Chicago-O'Hare to St. Louis over the past 5 years; in addition, Denver (the western hub) has been growing in importance relative to Chicago in United's overall system. Similar shifts by other carriers can be detected from Chicago to Kansas City, from Atlanta to Birmingham, from Dallas-Fort Worth to Houston, from Miami to Tampa, and from Memphis to Nashville. FAA, for its part, has been trying for years (with only limited success) to shift airline operations from Washington-National to Dulles International.

Market forces will continue to promote this redistribution, as will the traffic restrictions imposed by FAA at the 22 largest hubs as a result of the PATCO strike. Direct-service links already exist between most of these new transfer hubs, but the frequency and aircraft size of traffic between them would increase. Nevertheless, some hub airports will continue to experience higher than desirable levels of traffic and delays unless further measures are employed, such as peak-hour landing fees, access quotas, or slot-allocation schemes. Commuter airlines would be hardest hit by these restrictions, and even with new hubs available they would be hard pressed to improve service at existing points or add new service points to their networks. In addition, it would eventually be necessary to shift most GA traffic out of the top 20 or more airports (down to the supposedly "irreducible" 10 percent), which implies the need for improved facilities at reliever and other IFR-equipped airports if future GA growth is to be accommodated.

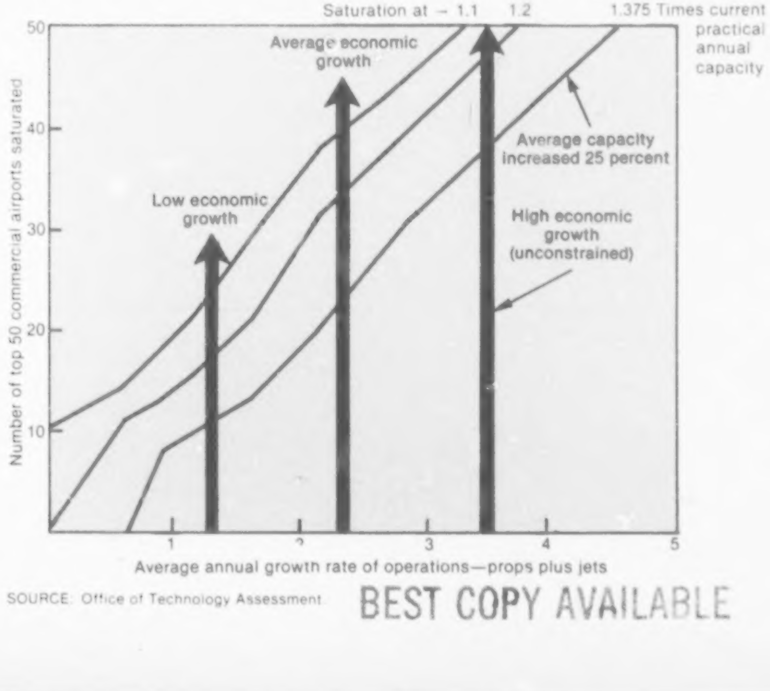
Expanded Capacity and Improved Management

The above scenarios indicate that attempting to accommodate expected aviation growth within the existing airport capacity will have mixed effects on the air service network. Although the adverse effects of growth, such as increasing delays or reductions in service, might be tolerable, it would nevertheless seem both prudent and desirable to increase capacity, where feasible, if this can be done at a reasonable cost and to the benefit of system efficiency. However, it is not feasible to supply the amount of new capacity required to eliminate or even appreciably reduce airside delay, particularly in major urban areas. In the short and long term, the alleviation of delay will be best achieved through tighter control over the level and distribution of airport operations, rather than the addition of new capacity (see ch. 6).

However, both commuter access and overall capacity constraints could be addressed by the construction of short, independent "stub" runways for turboprop aircraft where feasible, and especially at the most congested airports. This alternative (discussed in detail in ch. 6) would increase propeller capacity as an addition—rather than a detriment—to jet capacity, thereby reducing the severity of hub saturation and allowing GA and commuter aircraft to compete more effectively with jets for airport access. Figure 22 shows the effect of such runways in relieving saturation at commercial airports in 2000: by adding about 25 percent to the effective capacity of an average hub, they would allow a considerably higher level of traffic growth or, alternatively, reduce the number of airports saturated by any given level of economic and traffic growth. However, the addition of stub runways would also result in more complex traffic patterns, which might require new landing systems and improved traffic management in terminal areas.

Figure 22.—Number of Commercial Airports Over Capacity—Year 2000, 48 Contiguous States

(Jet plus propeller operations plus 10 percent allowance for general aviation)



SOURCE: Office of Technology Assessment

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Chapter 5

TECHNOLOGY AND THE FUTURE EVOLUTION OF THE ATC SYSTEM

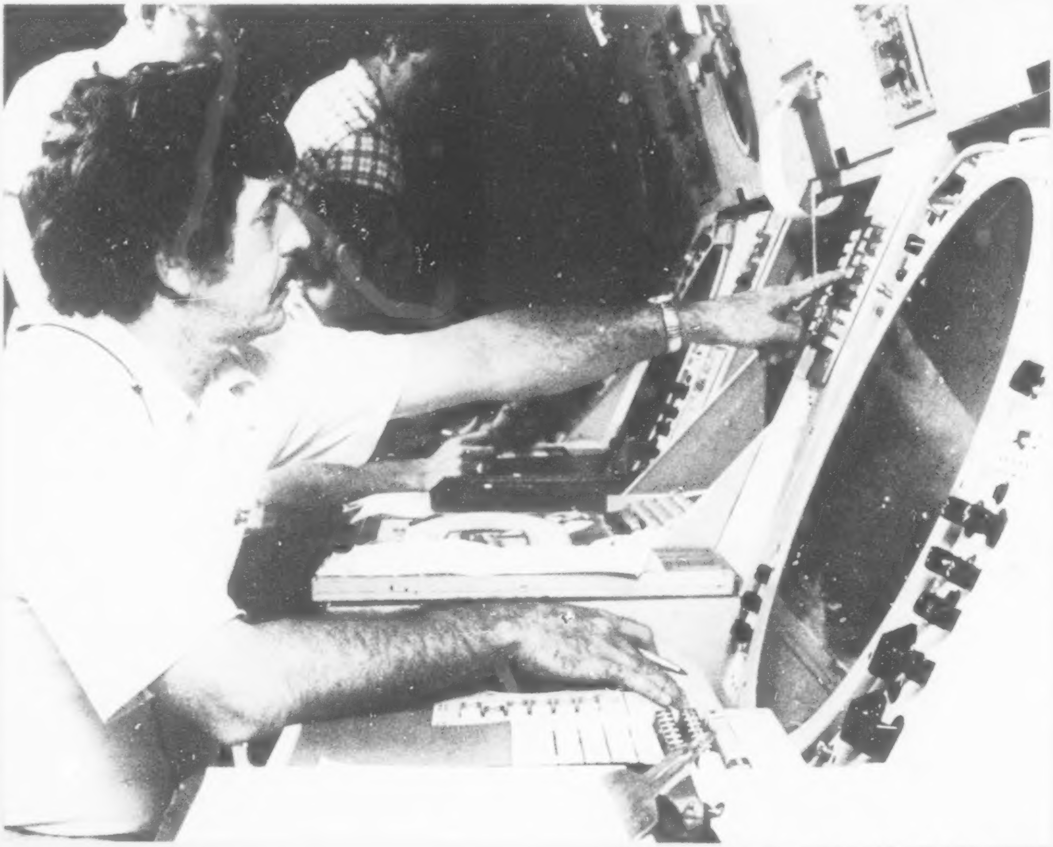

Photo credit: Federal Aviation Administration

Air traffic control

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Chapter 5

TECHNOLOGY AND THE FUTURE EVOLUTION OF THE ATC SYSTEM

INTRODUCTION

The present air traffic control (ATC) system has evolved over several decades from the one that was first put in place in the 1930's. The operational characteristics and organization of the original system were determined largely by the technologies then available—radio for navigation and air/ground communication, and telephone and teletype networks for distribution of information among ATC ground facilities. New technologies—such as surveillance radar, Air Traffic Control Radar Beacon System (ATCRBS) transponders, microwave relays, and electronic data processing—were added as demand increased and the state of the art progressed after World War II, but they did not change the essential characteristics of the earlier generation of air traffic control—a ground-based, labor-intensive, and increasingly centralized system.

Advanced data-processing and communication technologies have been introduced to meet the growing demand for ATC services* and to provide the controller with the information needed to make the decisions required for the safe and efficient movement of aircraft. However, these technologies were applied largely to improve the acquisition, integration, and display of information, or to speed its dissemination among ATC facilities. Recently, the automated transmission of certain types of information to pilots has also been introduced, e.g., weather and terminal area briefings. However, the making of ATC decisions and transmission of ATC messages have remained essentially a human function.

As the air transportation network grows and evolves in response to economic conditions, market forces, and changing Government regulation, the requirements for the ATC system will be affected in turn. In addition, new technological developments will make possible new functions and modes of operation that would have been impossible with older equipment and resources. The extent to which the system must grow depends primarily on the rate at which the level of air traffic and the demand for ATC services increase. There is considerable uncertainty on this score. The direction in which the system evolves will be influenced by what services are offered, how they are delivered, and how they are paid for. The answers to these questions, too, are subject to great uncertainty. Budgetary constraints and the continuing effects of the air traffic controllers' strike have introduced further complications. In addition, the evolution of the ATC system takes place slowly: some of the modernization programs now reaching fruition were first conceived a decade or more ago. During this period new technologies have become available, and there has been continuing controversy regarding the technical choices that will determine the character of the future ATC system.

This chapter presents an overview of some of the technologies and technological issues that are of concern in decisions that will soon be made about the future development of the ATC system. It is not a detailed treatment of the technological and engineering complexities of the subject, nor does it attempt to resolve any of the related economic and funding controversies. Instead, this discussion is intended to provide decisionmakers and the public with useful information about the implications of some of the advances in technology that have occurred or which are on the horizon. This information forms a background against which to assess FAA's 1982 revision of the National Airspace System (NAS) Plan.

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*These technologies have also found use in the cockpit where RNAV and other systems have provided capabilities that have indirectly affected the ATC system.

GOALS AND SERVICES OF THE ATC SYSTEM

In order to accomplish the goals of safety, efficiency, and cost-effective operation, the present ATC system offers the following services to the aviation community:

- *separation assurance*—tracking aircraft in flight, primarily with surveillance radars on the ground and airborne transponders, in order to ensure that adequate separation is maintained and to detect and resolve conflicts as they arise;
- *navigation aids*—maintaining a system of defined airways and aids to navigation and establishing procedures for their use;
- *weather and flight information*—informing users of the conditions that may be expected along the intended route so they may plan a safe and efficient flight;
- *traffic management*—processing and comparing the flight plans, distributing flight plans to allow controllers to keep track of intended routes and anticipate potential conflicts, and ensuring the smooth and efficient flow of traffic in order to minimize costly congestion and delays; and
- *landing services*—operating airport control towers, instrument landing systems, and other aids that facilitate the movement of air traffic in the vicinity of airports and runways, particularly during peak periods or bad weather that might affect safety or capacity.

These services together comprise an integrated program, no part of which can be fully effective without the others. Flight plans must take into account weather and traffic, for instance, and traffic must be routed to destinations so that it arrives on time and can be handled at the airport with a minimum of delay. Similarly, clearances have to be modified so that traffic can be routed around severe weather or away from bottlenecks that develop in the system. In a practical sense, the aircrew and ground controllers cooperate as a team using various human and electronic resources to maintain safety and to move traffic expeditiously. While the ultimate responsibility for safety of flight rests with the pilot, he remains dependent in many ways on data or decisions from the ground.

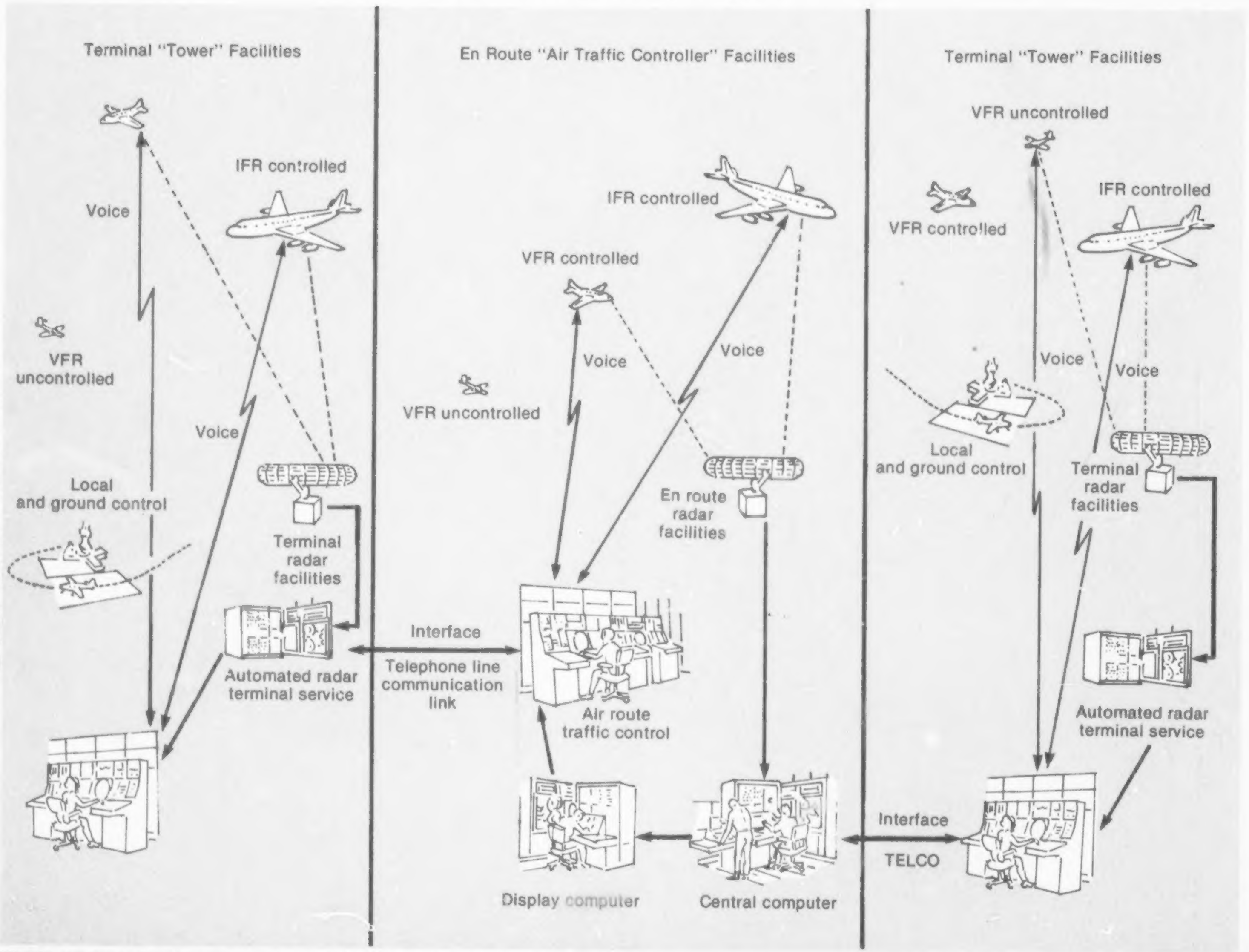
Photo credit: Federal Aviation Administration

One of the Nation's first air controllers—1929

MAJOR COMPONENTS OF THE EXISTING ATC SYSTEM

The present ATC system can be divided into two major subsystems: en route and terminal area (see fig. 23). The en route subsystem is primarily concerned with aircraft moving along the airway network, generally cruising at higher altitudes. To an increasing degree, it is also concerned with traffic flying point-to-point without following the airway network. The terminal

Figure 23.—National Airspace System


Terminal "Tower" Facilities
Voice
IFR controlled
VFR uncontrolled
Voice
Local and ground control
Terminal radar facilities
Automated radar terminal service
En Route "Air Traffic Controller" Facilities
IFR controlled
VFR controlled
Voice
Voice
VFR uncontrolled
En route radar facilities
Interface
Telephone line communication link
Air route traffic control
Display computer
Central computer
Terminal "Tower" Facilities
VFR uncontrolled
VFR controlled
IFR controlled
Voice
Voice
Local and ground control
Terminal radar facilities
Automated radar terminal service
Interface
TELCO

SOURCE: U.S. Senate Committee on Appropriations; FAA's En Route Air Traffic Control Computer System.

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area subsystem handles aircraft flying at lower speeds and altitudes as they arrive at and depart from airports, but it must also control IFR traffic that is passing through a terminal area without landing.* The major equipment components that support these ATC facilities are surveillance radar, airborne transponders, navigation aids, computers, and communication links.

Surveillance Radar

Two types of radar are used for the surveillance of aircraft. Primary surveillance radar (PSR) uses the return from the aircraft structure to determine range and bearing. Secondary surveillance radar (SSR), triggers a response from aircraft equipped with an ATCRBS transponder and is able to obtain, in addition to range and bearing, the aircraft's identity and altitude.** Because the transponder enhances the return from primary radar, it improves the controller's ability to track individual aircraft. SSR is the principal aircraft surveillance tool of the ATC system; PSR is used as a backup for SSR and for long-range weather data.

Airborne Transponders

The returns to surveillance radar vary considerably with range, aircraft structure, background clutter, weather, and several other factors. In addition, the present radar system does not permit aircraft altitude to be determined from the ground on the basis of raw return from primary radar. This makes it difficult to track specific aircraft using a reflective return alone, although computer processing can be used to isolate a moving aircraft from background clutter. Transponders are radio transmitters designed to respond to ground interrogation with a strong signal that can easily be distinguished from a purely reflective return. The ground equipment and airborne transponders constitute the ATCRBS.

Photo credit: Federal Aviation Administration

Air control in the 1940's using table top plots

Photo credit: Federal Aviation Administration

Air control using a modern console

Current procedures require that all aircraft operating in the busiest terminal control areas (TCA), or flying above 12,500 ft must be equipped with a transponder capable of reporting both an aircraft identification code and altitude, Modes A and C, respectively. These devices respond to a Mode C inquiry from an

---

*In a terminal control area, all traffic is controlled by the ATC system.

**Altitude data is available only from aircraft equipped with a transponder having Mode C and an encoding altimeter. Only about one-third of the transponder-equipped aircraft have altitude reporting capability.

ATCRBS interrogator by giving the altitude of the aircraft, reported to the nearest 100 ft as sensed by an onboard barometric altimeter. Transponders also have the ability to transmit one of 4,096 different identity codes in response to a Mode A query from an ATCRBS interrogator. Under Instrument Flight Rules (IFR) the code to be used is specified for each aircraft by the ground controller; for all VFR aircraft equipped with a transponder a common identifier code (1200) is used. Some blocks of numbers within the 4,096 identity codes are reserved for classifying traffic such as coast-to-coast flights. Other codes have been set aside for emergency purposes—aircraft that have lost radio communication, aircraft in distress, or hijacked flights.

Navigation

Navigation aids are another important element of the ATC system. Although they are not traffic control devices per se, they do have an influence on the structure and the operation of the system.* As described in chapter 3, the primary radio navigation aid is the very high frequency omnidirectional range (VOR) system that operates in the VHF band immediately below the frequencies used for voice communication. VOR ground stations provide coverage of nearly all the continental United States and adjacent offshore areas, and most aircraft that have communication transceivers also are equipped to use VOR for navigation. VOR equipment enables the aircrew to determine the bearing to the ground station. Distance measuring equipment (DME), colocated with VORs, emits signals that allow the aircrew to determine the distance to the station as well. A station where VOR and TACAN, the military navigation system that is functionally equivalent to VOR/DME but more accurate, are colocated is called a VORTAC. Other navigation systems that are available are listed in chapter 3.

Many large commercial transports, military aircraft, and a growing number of corporate, general aviation (GA) aircraft are equipped with inertial navigation systems (INSs) that permit them to navigate without primary reference to ground-based radio transmitters. INS-equipped aircraft are not completely independent of ground aids since VOR/DME, LORAN-C, or OMEGA navigation signals are used for periodic crosschecks of INS accuracy and realinement of inertial platforms.

A growing number of commercial and GA aircraft are being equipped with navigational computers that enable them to operate off VOR-defined airways along direct origin-to-destination routes. This capability for area navigation (RNAV) can be achieved either with an INS or with equipment that uses VOR/DME, OMEGA or other navigation aids as the primary reference. The ability to fly RNAV makes it possible to achieve considerable savings in time and fuel consumption, and also allows aircraft to avoid the congestion that sometimes occurs at VOR airway intersections. FAA has begun publishing RNAV routes for use by suitably equipped aircraft. At present, however, controllers grant direct clearances only to the extent that they do not conflict with traffic along airways or affect adequate separation. While FAA is making an effort to accommodate the increasing demand for RNAV clearances, there are still cases in which the limitations imposed by the present VOR airways system prevent users from realizing the full benefit of installed RNAV equipment.

Computers

Computers are used extensively throughout the ATC system to process flight plans, to correlate radar and transponder returns, to filter out extraneous signals that could obscure controlled aircraft, and to generate displays on the controller's console. All control decisions, however, are made by human operators. In the busiest terminal areas, an ARTS II or ARTS III computer system combines SSR data and flight plan information to create a display on an analog terminal (see fig. 23). Displayed alongside the position indicator for each aircraft is a data block that includes the transponder code of the aircraft, its altitude and groundspeed, and the aircraft registration number or flight designation *to the extent that they are available.* For example, none of these data will appear for an aircraft flying VFR without an operating transponder unless they are entered manually.

---

*For example, aircraft will follow radials to or from VOR stations. This tends to add some order to the flow of traffic even if it is not operating within the ATC system.

The principal computer used at the 20 en route ATC centers is the IBM 9020, an assemblage of IBM 360 components that have been modified for ATC applications. The technology incorporated in these machines is of 1962 vintage, and there have been considerable advances in the design and construction of computers since they were first built and installed. The IBM 9020s are tied to either IBM or Raytheon digital display subsystems that present radar surveillance and clearance information in a brighter, sharper image than the analog displays used in the terminal control facilities. In addition to driving the controller displays, the IBM 9020s also handle communications with computers in other en route centers and terminal area control facilities as well as other tasks such as flight plan processing.

In case of an IBM 9020 failure, the controllers have a backup system, called Direct Access Radar Channel (DARC), that digitizes the raw data from the secondary surveillance radar to create a comparatively clean image on the control consoles. However, to use DARC, the controllers must manually shift their display screens from the vertical to the horizontal position and make plastic markers ("shrimp boats") to identify the targets on the screen, because the DARC system cannot obtain the clearance data from which to generate a display of the aircraft call sign or intended route. If the DARC system is inoperable, controllers have a second backup, a broad-band system that displays radar data without computer enhancement and thus provides no data

Photo credit: Mitre Corp.

Computers for air traffic control system for aircraft en route block for individual targets. FAA has indicated that it plans to remove the broad band capability when sufficient operational experience with DARC has been established.

FAA is considering the option of installing compatible computer and display systems in the en route and terminal area control facilities. If this were done, much of the line of demarcation between these classes of facilities could be removed.

Communication

Communication is a key element in the present ATC system, and advances in communication technology may open new options for configuring the system in the future. Historically, voice radio has been the primary and almost exclusive means of communicating between aircraft and the ground. Digital communication—the transmission of data in the form of machine-readable binary signals—has come into use for linking ground stations (particularly for computer-to-computer interchanges), but it has not yet been applied for air-ground messages, except in the limited case of transmitting aircraft identity and altitude by means of ATCRBS transponders. In the future, it is expected that an air-ground digital data link will play an increasingly important role as the automation of ATC functions requires more direct communication between airborne and ground-based computers.

Another important advantage of the digital data link is that it permits messages to be transmitted selectively. The present voice-radio method is broadcast—i.e., available to any and all aircraft equipped with an appropriate receiver, regardless of the intended recipient. This "party line" feature has certain advantages, since it permits pilots to develop a sense of what is happening in the surrounding airspace. Nevertheless, a "discrete address" technology that permits messages to be sent to a specific recipient can be more effective than broadcast for processes that require computer-to-computer communication. This is the underlying principle of the Mode S data link (formerly the Discrete Address Beacon System, or DABS), which is an important building block in FAA's plans for future system development.

In the future, with the introduction of a digital data link capable of selective address, two distinct modes of communication can be expected. Broadcast, the mode now used, will continue for voice or digital transmissions of general interest, such as weather, airport status, and traffic advisories. Other transmissions, pertinent only to specific aircraft, will be sent by a discrete-address digital data link that allows isolation of specific receiving stations. However to the extent that communication relative to position and intent uses a discrete address data link rather than broadcast, the side benefits of the party line would be diminished.

The application of a digital data link is not limited to air-ground communication; it could also be used for exchange of messages between aircraft. For instance, most of the air-to-air communication in proposed collision avoidance systems would be digitized; and by allowing airborne computers to direct messages to specific aircraft, maneuvers intended to resolve conflicts could be coordinated between aircraft. Alternative plans for the implementation of a digital data link are discussed later in this chapter.

FUTURE REQUIREMENTS, OPPORTUNITIES, AND CONSTRAINTS

Future Requirements

The evolution of the ATC system will be influenced by changes in user demand, market forces, and regulatory policy, as well as the availability of new technologies and the possibility of applying them to achieve greater effectiveness of the ATC system through higher levels of automation. In many cases there are several ways of meeting specific needs, and the choice of which path to take will reflect a combination of technological, economic, and policy considerations. In general, however, prospective changes in the system will be dictated by three related technical requirements:

- *replacement of obsolete equipment*, which will become increasingly difficult to maintain and repair, with more modern equipment that offers higher reliability and might also provide greater flexibility, higher capacity, or lower costs;
- *increase of system capacity* in order to accommodate growth when and where it occurs, by improving the management of existing resources where feasible and by adding new resources where necessary; and
- *addition of new capabilities* in order to support improvements in efficiency and productivity by automating more functions and by introducing features that make it possible to take advantage of improvements in avionics and other newly available technologies.

Advances in technology have increased the number of options that could meet these requirements. *Computers* will probably assume roles of increasing importance, both in the air and on the ground, because they present opportunities to increase efficiency, productivity, or capacity by relieving human participants in the system of routine tasks, by facilitating human decisions, and by improving the timeliness and quality of information. As a result, the human operator's role will become more that of a manager of system resources than that of a direct controller of aircraft. *Communications* will also be a critical element, and digital communication between machines (computers and various avionic devices) will be at least as important as voice communications between humans. Future systems, therefore, may have to provide for one or more high-speed data links of sufficient capacity to handle the large volumes of data and messages that will be generated. *Collision avoidance* will receive increasing attention as the volume of traffic grows, and both *navigation and landing aids* may need to be upgraded in order to maintain safety and improve the efficiency with which airways and airports are utilized. Specific technical options for each of these functions are discussed in later sections of this chapter. The more general opportunities created by advanced technology are discussed below.

Technological Opportunities

The development of microelectronics has been a primary source of expanded technological opportunities for the ATC system. Data-processing capabilities can now be tailored to meet virtually any computational requirement, hardware costs have fallen significantly, and reliability continues to increase. The ATC system as presently constituted is highly labor-intensive; and since the PATCO walkout, the system has been kept operating with a greatly reduced work force only by administratively limiting traffic. Some observers have suggested that the current situation presents an opportunity to review the basic structure of the system and to apply new technology so as to make it less labor-intensive and less dependent on (or vulnerable to) the actions of any specific group within the work force.

Computer software figures prominently in the present ATC system and will have an even more significant role in the future as the need for new capabilities expands. Many systems related to the safety of flight, both ground based and airborne, will be "software driven," in that the processing of sensor data and the generation of displays will be more dependent on computer programs than is now the case. Processes running on different computers will communicate directly with one another. There will thus be a need for systems with the ability to identify errors and to take compensatory action automatically.* Present ATC software uses a combination of computer languages, but new high-level languages that are now available (like those used for military command and control) and those that will be developed in the future may make it easier and cheaper to implement, modify, and maintain ATC software.

Commitment to a highly automated mode of operation is not without risk. When there is a computer failure in the present system, the controllers can revert to manual methods and keep traffic flowing. However, experiments with more highly automated systems have shown that traffic levels can reach a point that, although well within the capabilities of the automated system, is beyond the point where they can be handled manually. At these traffic levels, controllers experience considerable difficulty in reverting to manual operations during computer outages.[1] This suggests that even though computer technology offers promise for the future, there may be a point of no return beyond which the commitment to automation is absolute—the only backup system for a highly automated ATC system is another highly automated system.

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*Systems with this type of capability are within the state of the art and some are available "off-the-shelf."

Decreasing size and costs of computers also mean, however, that data-processing capability can be located anywhere in a system, and that redundancy can be provided where exceptionally high degrees of reliability are required. Microprocessors have become integral elements of aircraft instrumentation, and modern aircraft can and do carry general-purpose computers that can be used for a variety of applications, such as flight management, processing digital communications with the ground or other aircraft, updating the navigation system, developing alternative flight plans, or driving multifunction cockpit displays that replace several electromechanical instruments. The introduction of these airborne capabilities means that ATC functions need no longer be wholly resident in ground-based computers. As a result, it might be possible to improve system operation and safety by redistributing these functions among the various participants in the ATC process. Many of these functions will be critical to the safety of flight and, therefore, the computer based systems that perform them will fall within the airworthiness certification program of FAA.

An ATC system that places more information and functions in the cockpit will also require changes in communication technology. As ATC automation becomes more widespread and more integrated into the system, digital data communication will come into greater use. Transmissions directed to a specific receiver—the principle underlying the proposed Mode S data link described later—would facilitate communication between ground-based and airborne computers. They would also allow a computer to continue with other functions once it determines that it is not the intended recipient, a feature that increases the effective capacity of a processor. The capacity required for data links between ground facilities would also need to increase. While telephone and other ground links are used at present, point-to-point satellite channels might provide an alternative in the future.

Satellites could also be used for aeronautical navigation and surveillance. Singly or in constellations, satellites with accurate sensors and computing capabilities can be used to determine aircraft position and relay the information to other aircraft and ground stations. Satellite-based collision avoidance systems have been suggested. Large satellites that support a number of functions are also being considered for civil aviation, notably in the Aerosat system of the

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[1] Leonard Tobias and Paul J. O'Brian, "Real-Time Manned Simulation of Advanced Terminal Area Guidance Concepts for Short Haul Operations," Ames Research Center, August 1977, NASA-TN-D-B499.

The experiments, conducted in 1971 at the Ames Research Center and jointly sponsored by FAA and NASA, were to determine the comparative utility of 3-D and 4-D RNAV as aids to flying landing approaches. Controllers and pilots were placed in a simulated high traffic environment and required to control traffic and fly approaches in STOL [short takeoff and landing] aircraft equipped with the two onboard navigation aids. Results showed that the performance of both controllers and pilots improved although the controllers were only secondary beneficiaries of the equipment installed in the aircraft.

Generally, when the effects of 4-D RNAV were compared with those of 3-D RNAV, two types of effects were observed. The first related to improvements in the effectiveness of both pilots and controllers. Pilots were able to fly a better track when assigned a route and a time to arrive at a checkpoint. The range of deviations of arrival time at a checkpoint from the time assigned dropped from about 4 minutes to about 30 seconds. Requirements for voice communication between controllers and aircraft under their control were cut by more than half. Traffic flows were more orderly, and the number of aircraft in the system increased by about 25 percent.

A second major conclusion was that there may be a point in the development of automated systems beyond which it is no longer possible to return to a manual back-up. At higher levels of traffic, it was more difficult for controllers to make the adjustments required to handle an emergency and restore traffic once the emergency had been resolved. Controllers expressed a definite need for more automated support for handling emergencies and restoring traffic afterwards.

From this it seems that automated systems may have to be built so that they are self-diagnosing, self-correcting and/or backed up with other automated systems. Such back-up systems may not offer all of the features of the primary system but would be adequate for an interim period while repairs to the primary system are underway.

European Space Agency. The reliability and longevity of satellites are high and likely to increase in the future. The space shuttle makes it possible to recover, refurbish, and relaunch satellites, or even make repairs while in orbit. However, the leadtimes for scheduling shuttle payloads will preclude its use in responding rapidly to unforeseen emergencies. In addition, frequencies and orbital slots are limited and ATC applications must compete with other potential users of space technology. Both NASA and FAA have spent considerable amounts on R&D for ATC satellite applications, but no significant U.S. program is currently under way. Much of the required technology is available, but it has not yet reached the point of being a cost-effective alternative to ground-based ATC facilities and configurations. At some point in the future, however, this may change and the option of using satellites in ATC applications may have to be reevaluated.

Constraints and Other Factors Affecting Future Evolution

Continuity of Service

ATC is an ongoing activity that cannot be interrupted while a replacement system is put into place. Any changes in the system must therefore be implemented gradually, and new and old equipment will have to be operated in parallel to assure continuity of service throughout the transition period. FAA can reduce the length of this transition period by mandating equipage by certain dates. If installation is voluntary, however, some users will hold off replacing existing equipment until it wears out, and some users might never make the change. At a minimum, parallel operation will be needed for perhaps as long as a decade while users install new equipment. In some cases, it could be in the best interest of all parties to establish a firm date on which existing services will terminate and by which all users will have to be equipped to use the new service.

Timing of Design Decisions and System Implementation

Identifying future needs and installing the facilities to meet those needs take a considerable amount of time. In periods of rapid technological progress, new equipment or facilities may become obsolescent before the implementation phase is completed. Redesigning the system to incorporate newer technologies, however, may take so long that a badly needed function remains unavailable, or that a deteriorating system is kept in place long after it has become inadequate. At some point, therefore, the decision to go ahead with system enhancements must be made, despite the realization that the incorporation of newer technologies will have to be deferred until a later cycle of system modifications.

The design and development of some prospective ATC systems and facilities began over 10 years ago, and it will be late in the present decade or early in the next before implementation can be completed. A substantial portion of the needed ground facilities would have to be installed before users would begin to install the required equipment on their aircraft, since they would see little benefit in spending money for equipment before it is of practical value. The rate of installation of airborne components would also be limited by the rate at which they can be produced, and the avionics industry would be unlikely to commit to production until it foresees a market of sufficient size to assure profitability.

User Costs

FAA is responsible for the design, procurement, installation, operation, and maintenance of equipment used in ATC installations and for establishing standards for the equipment to be carried on aircraft. However, the responsibility for and costs of procuring, installing, operating, and maintaining the airborne equipment rests with the users. Any adverse impacts on aircraft performance resulting from the installation of airborne equipment also translates into increased user costs. Decisions about changes to the ATC system must consider these user costs and the effect that required equipment might have on aircraft performance.

Large aircraft have the space to accommodate new avionics, but in small GA aircraft or densely packed tactical military aircraft space is at a premium, and room for additional equipment to meet the needs of the ATC system may be hard to find. Antenna location, in particular, often involves a tradeoff between aerodynamic and electromagnetic characteristics. For instance, the small blade antenna used for a standard ATCRBS transponder has little effect on aerodynamics, but the larger direction-finding antennas required for some collision avoidance systems may adversely affect aircraft performance or even structural integrity when retrofitted into existing aircraft.

Not all new functions require the replacement of existing equipment. Some experts suggest that the capabilities in existing equipment are ample for future needs and that new or upgraded equipment is not required. Some entrepreneurs have been successful in adapting existing equipment to new purposes without making any fundamental changes. RNAV, as mentioned, uses VOR/DME signals and existing receivers to obtain the data required for navigation outside the defined system of airways. Tri-Modal BCAS, a collision avoidance system, is designed to operate with the installed ATCRBS transponders and interrogators.

In addition, the ATC system serves a broad mix of users who operate aircraft having a wide range of performance characteristics and who use the airspace for a variety of purposes. Over half of all air operations are not under the control of FAA terminal and en route facilities, but the ATC system must recognize the existence of these "off system" activities so that the available airspace and airport facilities are used in a safe, efficient, and equitable manner. The heterogeneity of the user mix complicates both the design and the implementation of new systems, and the GA community is particularly sensitive to the issues of user costs and mandatory equipage.

Locus of Decisionmaking

Decisionmaking in the ATC system is distributed between ground controllers and aircrew. Ultimate responsibility resides with the pilot, but controller-supplied services are particularly important in high-density traffic and at times of poor visibility. Some pilots feel that the amount of ground control is becoming excessive and that they are burdened with the responsibility of operating the aircraft safely without having available the information required to meet that responsibility. Technologies now available or under development could make additional information available to both ground controllers and aircrew and might permit redistribution of the decisionmaking function. These alternative concepts have not yet been validated and tested; but they could lead to an ATC system that is less dependent on ground-based equipment and control decisions.

Freedom of Airspace and Equipage

The passage of time has also brought increasing limitations on the amount of airspace available for VFR operations. The GA community (traditionally vocal in this matter) has been joined by the military services, who believe that access to suitable training areas is becoming excessively restricted. The airlines, faced with high fuel prices and low profitability, have also argued that they should be permitted to fly the most fuel-efficient routes possible between points served.

While FAA has not required all aircraft to be equipped to participate in the ATC system, it has imposed limitations on the operations of aircraft lacking specific pieces of equipment. While the requirements are still minimal, freedom of airspace is already directly affected by the amount of avionics an operator is able and willing to install on an airplane. As more airspace becomes congested, the areas in which unrestricted VFR flight is permitted may have to be reduced, or some other method be found to assure separation and preserve safety of flight. It may not be possible in the future to permit the some degree of flexibility and freedom of airspace use that has been accorded in the past to those operating outside of positive control by the ATC system.

International Requirements

The United States is party to a number of international agreements that affect the operation of the air transportation system. It is legally obligated to provide ATC services that conform to international standards at gateway facilities unless airspace users are notified that particular exceptions are taken to the applicable agreements. Foreign-flag carriers enter U.S. airspace at gateway facilities with the understanding that they will receive full services if they are equipped in accordance with international standards. U.S. aircraft similarly expect a full range of services from foreign controllers. There is no legal obligation to operate the domestic ATC system in conformity with international standards, although many nations (including the United States) find it desirable to do so.

Two international bodies establish standards that affect aeronautical operations. The International Civil Aviation Organization (ICAO) promulgates standards that establish flight procedures and aircraft equipment specifications. For example, one ICAO standard governs the signal format used by each mode of the ATCRBS transponder. Mode S, the signal format of the DABS data link, is currently being considered for establishment as an ICAO standard, without which it cannot be implemented for international operations.

The second organization, the International Telecommunication Union (ITU), also establishes conventions that affect aeronautical operations, but the relationship is not as close as that of ICAO. ITU assigns portions of the radio frequency spectrum to various applications throughout the world. The spectrum is a finite resource, and competitition among alternative applications is intense. Aeronautical radio has been assigned bands that are of sufficient capacity to meet present needs, but it may be difficult to obtain additional spectrum allocations for new aeronautical applications in the future. However, it may be feasible to reduce the channel spacing in bands that are currently allocated and thus increase total effective capacity. One area where there is significant pressure is in the allocation of spectrum to satellite applications; and this may be a factor that could limit the development of ATC services that use satellites.[2]

Military Requirements

The ATC system will be constrained by national security considerations. In time of war the system must meet the needs of the military without aiding an enemy in locating and hitting targets in the United States. In addition, ATC equipment and facilities must not compromise the operational integrity of military equipment. The military is a full participant in the ATC system, and FAA is charged by law with ensuring that the system meets both civil and military requirements. Some arrangements for coordinating the activities of FAA and the Department of Defense (DOD) have been established, but these have not been completely formalized.

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[2] For further information on this subject see OTA's assessment, *Radiofrequency Use and Management: Impacts From the World Administrative Radio Conference of 1979* OTA-CIT-163 (Washington, D.C.: U.S. Government Printing Office, January 1982).

TECHNICAL OPTIONS

En Route Computer Replacement

The computer now in use at en route ATC centers is the IBM 9020, a designation given to a derivative of the IBM 360 line that has been specially modified to perform ATC functions. Although the IBM 9020 was first commissioned by FAA in 1974, it incorporates a technology that is close to 20 years old. It has less speed and capacity, is less reliable, requires more energy and floor space, and is not as easy to maintain as more modern computers that could be used in support of the ATC system.

Growth in the demand for ATC services has exceeded the data-processing capability of the IBM 9020. Some ARTCCs are already operating at capacity, while others are expected to reach capacity later in this decade. Alleviating capacity problems by acquiring additional IBM 9020 computers is not a practical alternative, since the IBM 360 has been out of production for several years. Buying used IBM 360s and modifying them to make them IBM 9020s would be expensive in the short term and would provide, at best, only a stopgap solution.

The reliability of the IBM 9020 hardware and software has also been troublesome, giving rise to concern that the cost of repairing and maintaining the system will become excessive. As time passes and existing stocks of spare parts are exhausted, maintenance of the computers could become very expensive because spares would have to be fabricated to order. Similarly, the task of modifying and maintaining software to meet evolving needs is likely to be increasingly difficult to perform. In the future, it will be difficult to recruit and retain programmers capable of maintaining the software because those who are best able to do this job prefer to work on more modern equipment. Further, there is ample demand for their talents outside of FAA.

FAA is now in the process of planning the procurement of a replacement computer system that will overcome present operational problems and provide additional capacity to meet the needs of the en route centers during the last decade of this century and into the next. Plans are to use the increased capacity of the replacement computers to provide a variety of new and improved services, as well as to satisfy the requirements generated by the anticipated increase in aviation activity. Table 6 indicates the range of services and activities FAA expects to support with the replacement computer system. These applications fall in three major areas: control of individual aircraft, conflict alert and resolution, and management of traffic flow.

The basic technical issue is not whether the 9020 system needs to be replaced—there is wide agreement that it does—but what replacement strategy should be pursued.

There are many strategies for replacing the IBM 9020s, but all can be placed in one of three groups:

- replace all hardware and software simultaneously;
- place initial emphasis on the replacement of the hardware; or
- place initial emphasis on the replacement of the software.

The first strategy—total replacement—implies that the present system, with minor modifications needed to keep it operating, will be kept in place until the replacement hardware and software are ready for commissioning. The latter two strategies are incremental approaches that provide for a transition to the new system in comparatively small steps over an extended period. Some believe that either of these strategies, if successful, could provide relief from the most pressing problems within a period of 3 to 5 years, as opposed to the more than 8 years required for the total simultaneous replacement option.

The en route computer replacement strategy has been reviewed as part of the FAA effort to produce a revised NASP. Implicit in past FAA statements is the presumption that the replacement computer, like the IBM 9020s, would have to be uniquely designed for ATC applications. Critics of the full replacement strategy have put forth options that would effect the replacement of the computers incrementally.[3] Generally, these plans envision using off-the-shelf equipment to replace the IBM 9020s rather than obtaining a computer that has been designed or modified specifically for ATC applications.

Total Replacement

The total replacement strategy has much to recommend it. First, FAA has learned from its experiences with the present system and, given the opportunity to make a fresh start, would be in a position to design a replacement that would correct present weaknesses. Second, advances in hardware, software, and communication technologies have created new options that were not available when the present system was installed. A complete replacement of the present system

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[3] See, for example, *FAA Air Traffic Control Computer Modernization*, Hearings before the Subcommittee on Transportation, Aviation, and Materials of the Committee on Science and Technology, U.S. House of Representatives, June 16-18, 1981.

Table 6.—Perform ATC Automation Processes

Sustain ATC system operation	Assemble system information: • Acquire or negotiate decisions • Collect and analyze system status information
	Calculate state of ATC system: • Calculate system load • Predict system state
	Resolve management actions: • Resolve differences in system state and decisions • Translate resolutions into automation directives
	Manage ATC automation processes performance: • Formulate required processes actions • Monitor processes status and performance • Monitor plan status and performance
Perform ATC planning processes	Assemble planning information: • Assemble trajectory information • Assemble flow information • Create multidimensional profile
	Identify strategic planning problems: • Predict strategic delays • Predict long-term conflicts
	Resolve strategic planning actions: • Absorb strategic delays • Resolve long-term conflicts
	Issue strategic planning actions: • Formulate clearance plan
Perform ATC controlling processes	Assemble control information: • Assemble control information • Convert to appropriate reference • Apply control conditions
	Identify control problems: • Predict short-term AC/AC conflicts • Predict environmental conflicts • Detect track/trajectory deviations
	Select control actions: • Assess "accept/handoff" situations • Resolve tactical situations • Generate clearances
	Control ATC system: • Perform aircraft accept/handoff • Deliver clearances • Deliver advisories

SOURCE: *ATC Computer Replacement Program System Level Specification (Preliminary): En Route ATC Automation System* FAA-ER-130-003, May 1981 (draft).

offers the opportunity to explore all of these options fully and to select the one that best suits ATC requirements in terms of both technical characteristics and overall system productivity.

On the other hand, the total replacement option would do little or nothing to relieve the deficiencies of the present system in the short term. If procurement were to start immediately, it is unlikely that the first replacement computers would be in operation before the end of the decade. In the interim, the IBM 9020s would have to be kept in operation to meet the ongoing needs for ATC services—a task that could become increasingly difficult and costly.

Critics of FAA have pointed out that the number of interruptions to service experienced with the present computers constitutes a threat to the safety of flight.[4] A more recent study by the National Transportation Safety Board[5] indicates a significant decrease in the number of computer outages since the controller strike in the summer of 1981 due in part to the subsequent reduction in the level of traffic. Concern with the reliability of the ATC computers remains, however, and FAA has pointed out that some of the en route centers were approaching capacity limits at the time of the strike. This last consideration would favor a conversion strategy that will have a positive short-term effect on en route traffic capacity.

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[4] *Air Traffic Control Computer Failures*, Committee on Government Operations, U.S. House of Representatives, House Report No. 97-137, June 11, 1981.

Hardware-First Replacement ("Rehosting")

Either of the alternative strategies for the incremental replacement of the computers entails a number of assumptions about the structure and operational characterstics of the present system. For example, a proposal to move some of the functions from the IBM 9020s to an auxiliary computer assumes that it is possible to isolate the software elements that perform those functions from the rest of the IBM 9020 software. A proposal to move the existing software to a new processor assumes that interface problems arising from differences in the internal timing of the machines can be overcome. Such assumptions are critical both to the feasibility of incremental replacement strategies and to the schedule and budget to carry them out.

The second option—incremental replacement with initial emphasis on substituting new hardware—would "rehost" or move the existing software to a new processor capable of supporting the IBM 360 instruction set. Several manufacturers produce machines with this capability, but in every case some modification of the existing software would be required.* At a minimum, some allowance would have to be made for handling the instructions unique to the IBM 9020. Real-time applications, such as the ATC software, are characteristically sensitive to the timing of internal machine operations, and this too could cause severe problems in rehosting the software. There could also be problems in meeting the requirements of the interface between the main processor and the IBM or Raytheon systems that drive the displays used by the controllers. However, there are probably technical solutions to these problems given enough time and resources to work them out.

Even though there may be problems with rehosting the existing software in a new processor, there are several points that recommend this strategy. Some suggest that this approach could be implemented by 1985. Second, once the constraint of machine capacity has been relieved, it would be possible to begin restructuring the software to improve its maintainability and reliability. Finally, the replacement computer could be selected with a view toward providing enough additional capacity to support the new functions and services planned by FAA as part of longer term improvements of the ATC system.

The "hardware-first" approach does not rest on the assumption that the processor to which the ATC software is moved would necessarily be the long-term replacement for the IBM 9020. It could be viewed as an interim replacement that would serve while FAA proceeded with a procurement program for a totally new hardware and software package, to be commissioned around the turn of the century and intended to serve well beyond the year 2000. On the other hand, the procurement of an interim computer replacement would involve a sizable investment that might, for budgetary reasons, effectively foreclose the option of initiating a second round of computer replacement after the interim system was put in place.

Software-First Replacement ("Offloading")

The strategy emphasizing the replacement of the software first would involve separating individual functions of the existing software. This of itself would be beneficial, since it would make it easier to maintain the existing software and provide an opportunity to increase overall operating efficiency. Weaknesses in the software that are known to have contributed to service interruptions could also be corrected during this initial reworking of the existing software. Once this initial phase had been completed, the software could either be rehosted intact in a new computer, or some functions could be offloaded from the IBM 9020 to another processor. The offloading approach would free capacity on the IBM 9020, allowing it to absorb increases in workload due to higher traffic levels.

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[5] *Air Traffic Control System, Special Investigative Report*, NTSB-SIR-81-7 (Washington, D.C.: National Transportation Safety Board, December 1981).

*The ability to modify software rests on an understanding of the existing structure and the procedure it executes in performing required functions.

In the short run, this strategy makes no provision for adding the new functions envisioned by FAA. However, as various functions are moved from the IBM 9020s to other processors, there would in effect be an incremental replacement of the present computer. This would offer considerable latitude in specifying the replacement processor. It could be a large main-frame processor to which elements of the ATC system could slowly migrate. Alternatively, the migration could be to several smaller processors, so that the system would finally evolve into a network of distributed, modular processors. Compared to the hardware-first strategy, this one offers the opportunity to migrate to a system that has been selected specifically to meet the requirements of the ATC application. Since the software would be designed first, and then a computer configuration suited to supporting it selected, it would be less likely that a second conversion would be required or that the resulting system would be less than optimal in terms of its ability to meet the long-term needs of the ATC system.

A potential disadvantage of this strategy, however, it that it depends on being able to separate specific functions in the existing software. There are indications that the subroutines within the present ATC programs are strongly interdependent, and that it might therefore be very difficult to modularize the present software system. If this is true, then it might be necessary to essentially rebuild the existing software in order to implement this strategy; and the cost of doing this could be prohibitive relative to other available options.

Modularity and Other Concerns

The total system replacement strategy advocated by FAA in the past recognizes the need to replace the controller displays and other peripherals, as well as the 9020 mainframe. ETABS, the electronic display of flight strip information, and other display features planned for the controller suite require replacing not only the main computer but the computers that generate displays as well. In addition, FAA is contemplating eventual replacement of the ARTS II and ARTS III computers now used in the terminal areas.

The ATC functions performed by computers in the en route centers and those performed in the terminal areas are similar. Therefore, one might consider procuring a computer for the en route centers that could also be used in the terminal areas. Most manufacturers produce lines of compatible machines with a considerable range of capacity. Thus, the concept of using a smaller version of the en route computer in the terminal areas could be attractive. In fact, such a strategy could reduce the overall costs of software maintenance for the ATC system because there would be fewer software packages in use.

At some point, FAA will incur the cost of replacing the IBM 9020s now installed in the en route centers. Operational factors create considerable pressure to begin doing so in the near term. However, once the initial conversion has been completed, future steps to upgrade or to modify the system could be accomplished at a slower pace. Manufacturers of computers generally design them so as to provide paths by which users can upgrade capabilities incrementally without large-scale rebuilding of software. Such avenues would be available to FAA in the future so long as off-the-shelf hardware was selected to replace the IBM 9020s. If, on the other hand, a unique processor were to be selected, it is likely that second conversion—of a magnitude similar to the one now being undertaken—would be required at some point in the future to support new ATC services and capabilities.

Automated En Route Air Traffic Control

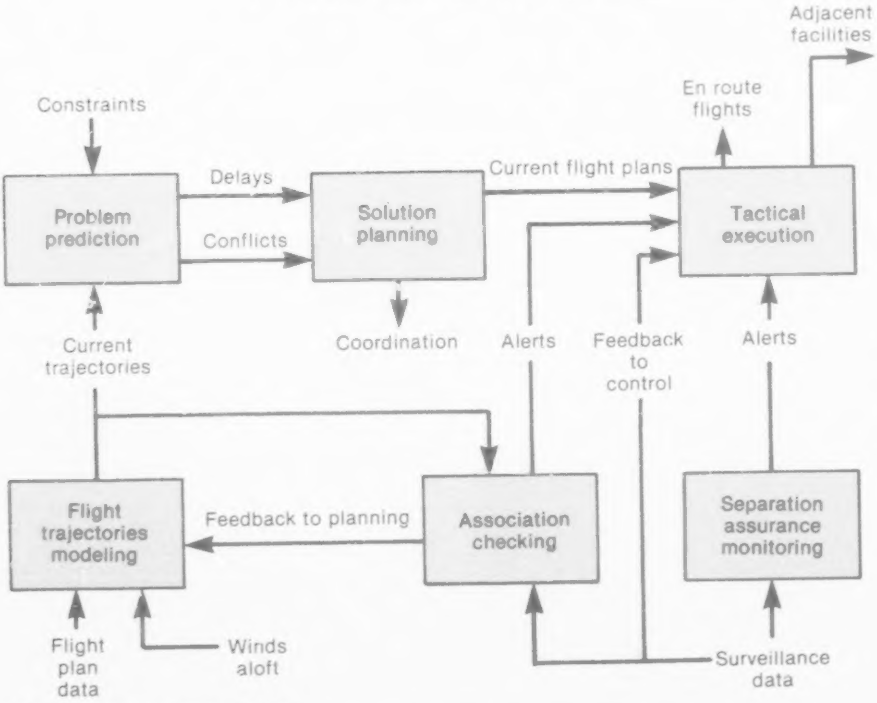
Another factor influencing the selection of the en route computer replacement is its compatibility with the long-term evolution of the ATC system. The future requirements and operational characteristics of the en route portion of the

ATC system are currently defined by FAA under the concept of automated en route air traffic control (AERA).

The essence of FAA's AERA concept is to automate the functions of maintaining aircraft separation, metering traffic flow, delivering clearances, and transmitting ATC messages. These functions would be assigned to computers, thereby relieving the controller of many routine tasks. The controller's role would then be primarily to handle exceptions and emergencies and oversee (manage) the operation of automated ATC equipment. Operationally, AERA would perform four principal functions: 1) automatically produce a clearance for each aircraft operating in positive control airspace that would ensure a conflict-free, fuel-efficient flight path; 2) formulate messages to aircraft needed to execute the planned flight profile and to assure separation; 3) transmit those messages by data link or VHF voice radio; 4) and monitor actual flight movements relative to flight plans, revising those plans and clearances as necessary to ensure continued freedom from conflicts. Major AERA functions are summarized in figure 24.

As currently envisioned, AERA would be a continuation and extension of the present ground-based ATC system. It could be implemented incrementally over an extended period automating first those functions that are most routine and repetitive for the human controller. Instructions to ensure separation and coordinate traffic flow would still come from ground facilities. However, these instructions would be formulated and issued by computers operating under the supervision of human controllers. Further, the control instructions would be derived from a more extensive data base (geographically broader and covering a greater span of time) than the present system. In effect, the AERA system would operate strategically—planning overall traffic flow as well as individual aircraft movements so that conflicts do not arise—although some form of tactical control would also

Figure 24.—Major AERA Functions


Adjacent facilities
En route flights
Constraints
Delays
Current flight plans
Problem prediction
Solution planning
Tactical execution
Conflicts
Current trajectories
Coordination
Alerts
Feedback to control
Alerts
Flight trajectories modeling
Feedback to planning
Association checking
Separation assurance monitoring
Flight plan data
Winds aloft
Surveillance data

SOURCE: Federal Aviation Administration.

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be provided in order to resolve potential conflicts before backup collision avoidance systems would be activated.[6]

While AERA would entail extensive ground-based data-processing capability, detailed analysis of aircraft flight plans, and close surveillance of actual flight paths, it would not necessarily lead to undue restrictions on aircraft movements. As envisioned, AERA could in fact reduce or eliminate many of the procedural constraints now imposed on the use of airspace. It would be a system of management by exception, in which controller intervention would be limited to situations (or localities) where conflicts could not be reliably resolved by computer routines. The controller would not have to visualize or direct overall traffic patterns, as in the present system, because the AERA concept envisions automated planning, monitoring, and metering of traffic flow in a four-dimensional region made up of several airspace sectors over an extended period of time.[7]

Potential Benefits

Initial estimates of the benefits of AERA indicate important savings in two areas: fuel savings due to more direct routings and reduced labor costs. The fuel savings for domestic airlines could be on the order of 3 percent; at present fuel prices, this would amount to a $250 million reduction in annual fuel costs.

The principal benefit to the Government would come in the form of increased controller productivity and the attendant reduction in operating costs: the volume of airspace assigned to a control team could be greatly enlarged; it might also be possible to reduce the size of the control team by automating the routine tasks of clearance coordination and flight data entry. Preliminary estimates are that controller productivity could be doubled, i.e. that individual en route controllers could handle perhaps twice as many aircraft as with the present system.[8] This in itself would not necessarily increase the capacity of the system, but it could significantly reduce future operating costs. One recent estimate places these savings at $300 million annually (1979 dollars),[9] but these preliminary figures would need to be refined as the AERA program progresses and a more precise picture of its operational characteristics is obtained.

A third advantage of AERA—and a strong part of the rationale for seeking a high level of automation—is that it would help reduce system errors.* In the present ATC system about 60 percent of these errors are attributable to mistakes on the part of controllers: improper coordination between controllers, inattention, forgetting, failure to communicate, poor judgment, and the like.[10] The underlying causes of many of these errors can be traced to the nature of ATC as a work activity—routine, repetitive tasks requiring vigilance and close attention to detail, and often conducted at a forced pace. Computers are ideally suited to this kind of activity; and if the tasks to be automated are judiciously selected and the software carefully designed, an automated system such as AERA could eliminate a major part of system errors, or at least provide a backstop to the shortcomings of human operators. In this sense, AERA is expected to be safer than the present system of traffic control.

Potential Implications and Issues

It must be emphasized that AERA is still in the early stage of engineering development. Extensive effort, over perhaps 5 to 10 years, will be needed to bring AERA to a precise and detailed definition of requirements and equipment specifications. Installation, test, and full operational deployment will take an additional 5 to 8 years.

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[6] R. A. Rucker, *Automated En Route ATC (AERA): Operational Concepts*, MTR 79W00167, The Mitre Corp., May 1979.

[7] L. Goldmuntz, et al., *The AERA Concept*, Economic and Science Planning, Inc., for the Federal Aviation Administration, December 1980.

[8] Personal communication, S. B. Poritzky, Director, FAA Office of Systems Engineering Management, Dec. 21, 1981.

[9] Goldmuntz, op. cit. This benefit is calculated by taking the $375 million annual expense (1979) to operate ARTCCs, increasing it by a factor of 1.6 to account for traffic growth by the time AERA would become operational taking 50 percent of that as the benefit due to AERA productivity improvements.

*By FAA definition, a "system error" occurs whenever the actual horizontal or vertical separation between aircraft is less than prescribed minima.

[10] Goldmuntz, op. cit.; and G. C. Kinney, M. J. Spahn, and R. A. Amato, *The Human Element in ATC: Observations and Analyses of the Performance of Controllers and Supervisors in Providing ATC Services*, MTR-7655, The MITRE Corp., December 1977.

Thus, AERA cannot be expected to replace the present generation of en route ATC until sometime near the end of the century. Similarly, the development costs and subsequent expenditures for facilities and equipment (F&E) have not yet been estimated, except in the most general terms. The latest available projections of R&D expenditures for en route control systems over the coming 10 years, much of which would be for AERA, show a total outlay of $170 million (1980 dollars).[11] As of the writing of this report, detailed estimates of the required F&E investments and costs to users for avionics appropriate to AERA have not been published.

Three major implications of AERA are already apparent, however. One is that AERA would require computer capacity and software far beyond what is now available in ATC applications, although not beyond the present or foreseeable state of computer technology. Second, AERA will require a two-way data link capable of rapid and high-volume exchange of information between the air and the ground. FAA now envisions that Mode S will provide this data link, and plans for AERA are predicated on the availability and widespread use of Mode S by the early 1990's. (See the discussion of "data link" in the following section.) Third, AERA implies equally extensive automation in terminal areas and in a central flow management facility capable of coordinating traffic throughout the ATC system.

This last point is particularly important both for the immediate plans to replace en route computers and for the design of the entire ATC system over the long term. It implies a modular computer architecture, in which en route and terminal facilities utilize similar hardware and software. This would make possible a flexible system design, in which individual modules would be capable of mutual support and backup in the event of local equipment or software failure. Human controllers would have difficulty operating the ATC system manually in the event of a failure of AERA if adequate automated backup were not provided.

The development and implementation of AERA is likely to raise several important issues. Some are technical and concern the reliability and safety of AERA, specifically its vulnerability to undetected software errors or hardware failures, and the adequacy of current hardware and software design techniques. The degree of automation envisioned for AERA may also be controversial, and this could give rise to issues pertaining to the division of tasks between human operators and computers or the design of the man/machine interface. The design will have to include features that keep the controller's attention and insure that he has enough information to deal promptly with anomalous situations as they arise. Acceptance of the system by both controllers and airspace users may prove to be troublesome.

A third set of issues pertains to the costs and benefits of AERA, especially the savings in operational costs ascribed to AERA in comparison with the investments needed to implement the system. A corollary question will be the costs and benefits to various classes of airspace users, especially if AERA entails mandatory equippage with data link or other avionics in order to participate in the automated ATC environment. Resolution of these issues, rather than the somewhat narrower questions of technical feasibility or system design, may prove to be critical to the acceptance and success of the AERA concept.

Data Link

Potential Benefits

Communication is central to the ATC process, and at present voice communication is the primary medium even for messages that involve computers processes. For example, a controller reads data from a computer-generated display, transmits it by voice radio to an aircraft, and the crew then enters the data manually into an onboard computer. This process wastes crew and controller time and is prone to reading or transmission errors. As the ATC system changes to incorporate higher levels of automation, therefore, great benefits could be gained from a digital data link that permits direct communication between automated components. Among these potential benefits are the following:

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[11] *National Aviation System Development and Capital Needs for the Decade 1982-1991* (Washington, D.C.: Federal Aviation Administration, December 1980).

- Digital messages can include special codes to detect and correct transmission errors.
- Processes that are running on computers can exchange data of little immediate interest to the human participants without human involvement.
- Digital transmissions can be addressed to a specific recipient such as an aircraft without diverting the attention of others to whom the information is not of concern.
- Digital messages can be transmitted, stored by the receiving terminal, and recalled on demand by the recipient.

In the present ATC system, the ATCRBS transponder provides limited data communication. Digital messages are sent by the transponder in reply to interrogations from the ground that request aircraft identity (transponder code) or altitude. Some observers, as discussed later in this section, argue that the inherent capability of the ATCRBS transponder is currently underutilized and that it is capable of meeting many of the future requirements for a digital data link. Others, including FAA and a significant segment of the user community, question this conclusion.

While there is little dispute that a data link is needed for the ATC system of the future, there is considerable discussion on how it would best be implemented.* FAA has suggested the addition of a data link capability—Mode S—to the specifications for the standard ATCRBS transponder. Others have suggested alternatives, and one organization, Aeronautical Radio, Inc. (ARINC), is now operating a nationwide data link that is used by the airlines for administrative communication. These alternatives are described in the sections that follow.

Mode S

The operating characteristics of the ATCRBS transponder conform to a standard established by the International Civil Aviation Organization (ICAO). For civil aviation, four modes of operation are defined, of which only two are in actual use: Mode A for aircraft identity, and Mode C for aircraft barometric altitude. Interrogation messages are formatted so that the transponder will recognize the mode of the query and reply appropriately. Since the transponder is already the primary link between ATC computers on the ground and aircraft in flight, it is logical to argue that the data link function be incorporated in the transponder.

FAA has suggested adding a fifth mode, Mode S, to the specification for the ATCRBS transponder.** This mode would provide a general-purpose data link designed to operate in a manner compatible with the existing ATCRBS modes. Mode S was on the agenda at the April 1981 meeting of the ICAO Communications Division, and position papers relating to it have been circulated among members. Great Britain and the Soviet Union have independently developed data link specifications that are compatible with Mode S. As of now, however, no member of ICAO has formally proposed detailed specifications that could be adopted as a Mode S standard.

Mode S permits a digital message to be addressed to a specific recipient. Each aircraft would have a permanently assigned code to identify itself in all ATC-related communications using the data link. When a Mode S interrogation or message is sent, replies from all transponders operating in Modes A and C are suppressed. Thus, during any transition period, interrogations cycles would have to be divided between Mode S interrogations and those in the existing Mode A and Mode C formats.

One of the applications of Mode S is for the surveillance function of the ATC system. When two aircraft are in proximity (i.e. in line or almost in line and differing in range from the interrogating ground station by 1.5 miles or less), their replies to a Mode A or C interrogation will interfere with one another, creating what is called "synchronous garble." The ability to address the interrogation to a specific aircraft is one method of resolving this difficulty. Other methods, such as computer processing of returns or the use of multiple sensors, can accomplish much the same thing.

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*Data links are also used to connect computers at the various ATC facilities operated by FAA. They use leased commercial telecommunication facilities at the present time; but in the future, satellites might be used to perform this function more efficiently. For this discussion, which will focus on data links for air-to-ground and air-to-air communication, the links between the ground-based computers are not of direct interest.

**Until recently, Mode S was referred to by FAA as DABS (Discrete Address Beacon System).

A second anticipated benefit from Mode S would be the ability to deliver control messages, such as clearances and en route weather information, to specific aircraft. The data needed to generate onboard displays of traffic could also be transmitted using this technique. Further, a Mode S data link could be useful in an exchange of data between aircraft, allowing them to coordinate conflict-resolution maneuvers (i.e., as an element in a collision avoidance system). Again, however, Mode S is not the only means by which these needs could be met.

Modes B and D

Most of the cost of implementing Mode S would be borne by the users, although some expenditures by FAA for the modification of its computers and software would be required. Some observers, however, consider the expense required for the introduction of Mode S to be unwarranted. They argue that the capability of the present ATCRBS transponder is underutilized. Modes B and D, it is suggested, could be used for some data link purposes, since they have sufficient capacity to meet the needs of the ATC system and would require no change in the existing ICAO specification. In addition, the message format for Modes B and D is shorter than that suggested for Mode S, and therefore less likely to result in the interference that might occur between Mode S transponders replying to simultaneous interrogations from different stations. However, in considering this alternative, one should also note that existing transponders do not include the components needed to process Mode B and D interrogations and would have to be modified (at users' expense) to do so.

VHF Data Link

A second alternative to Mode S is the use of a part of the VHF radiofrequency band assigned to aeronautical voice communication. ARINC, a corporation organized and owned by the airlines to provide communication services, already operates a data link of this type, know as ARINC Communication Addressing Reporting System (ACARS), which is being used by airlines for administrative messages. At present, small printers in the cockpit are used to record ACARS messages. A future modification could be conversion of the onboard weather radar screen or one of the multipurpose displays used by electronic instrument systems found in some aircraft to double as a display for ACARS messages.

Some critics suggest that ACARS would not meet the requirements for an ATC data link, pointing out that the VHF voice band is already crowded and that the one frequency used by ACARS (although currently underutilized) would not have sufficient capacity to meet the needs of the ATC system. This deficiency could be overcome by assigning multiple frequencies and scanning them automatically to detect incoming messages. There has also been a start (for reasons having little to do with data link) at reducing the current 50 kHz spacing in the VHF band to 25 kHz, effectively doubling the number of channels available. Some of these new channels could be allocated to the data link function.

Potential Implications and Issues

A data link is a primary resource that can be applied in a number of ways, and the benefits obtainable will be a function of the purposes to which it is applied. If the data link is to be used primarily for surveillance, then it would be advantageous to integrate it with the radar beacon system. On the other hand, if it is used primarily for nonsurveillance purposes such as delivering clearances, reporting weather conditions, or sending and receiving advisories, the need to associate it closely with the radar beacon system is less compelling. The balance in traffic between the uplink and downlink is also significant. If the great majority of the message traffic is "up"—from ground to air—the ground station could assume responsibility for allocating time among users. If there is a substantial flow of information in the opposite direction—air to ground, with a large part of it initiated by aircraft—the task of coordinating the activities of the users would become much more difficult. The latter situation would be complicated further by the introduction of substantial amounts of air-to-air traffic, as in the Traffic Alert and Collision Avoidance System (TCAS) concept (described later).

In considering the candidate forms of data link, another important consideration to keep in mind is that the data link is not an isolated subsystem of ATC, nor does it provide any unique service. Some form of data link is indispensible to the future scheme of operation and services envisioned by FAA, such as AERA and the collateral improvements of terminal area control and central flow management. The level of automation and the degree of strategic and tactical control that AERA would bring about requires a high-speed and high-volume flow of information, decisions, and replies between the air and the ground. Thus, even though FAA is committed to Mode S, it is important that all questions about data link be promptly resolved and that the necessary ground facilities and aircraft avionics be put in place so as to keep pace with the parallel computer replacement program. Both of these resources will have to be available within a decade if longer range improvements are to be accomplished in the 1990's.

It is also important to recognize that the data link decision is not one where the United States can act with complete independence. ATC requirements and development programs of other nations must also be considered, and the direction chosen by FAA must be coordinated through ICAO to ensure compatibility of signal format, modes of operation, equipment characteristics, and the like. On balance, a data link system that is compatible with the needs of other ICAO member nations is preferable to one that is unique to the United States.

Another important aspect of the data link decision concerns the avionics equipment that airspace users will have to install in order to take advantage of the services that data link offers. The data link is more than just a special kind of high-speed receiver-transmitter: to make any meaningful use of this capability, aircraft will also have to be equipped with processors to encode and decode messages, and with some kind of input-output device (displays and controls) that presents information to the aircrew and allows them to interact with the onboard processors and ground stations. Such equipment is costly to acquire (about $10,000 for a commercial aircraft, but somewhat less for GA) and would require special maintenance. For commercial and corporate operators the expenses of acquisition and maintenance could be absorbed without great difficulty, and the costs would probably be offset by operating benefits such as fuel savings, avoidance of delay, and greater flexibility of flight planning. For smaller GA operators, on the other hand, the cost-benefit equation may not be as favorable, and they may consequently conclude that the expense is not justified by the improved services or operational savings made available to them.

The matter could become particularly acute for GA if equipage with data link avionics were to be made mandatory for access to airspace or for receipt of essential ATC services. FAA currently envisions a tiered program of services in which users receive progressively more extensive service in relation to the sophistication of the avionics carried on the aircraft. The concern of GA is that the areas in which they will be allowed to operate with only minimal equipment (that is, without a two-way data link) will become so restricted that small GA aircraft will be effectively excluded from the Nation's airspace. The extent to which these concerns are warranted will depend heavily on the type of data link that is selected and how it is to be incorporated in various classes of aircraft.

Collision Avoidance

A primary function of the ATC system is providing separation assurance. Ground-based surveillance equipment and computer software include features that will alert the controller to situations where separation standards have been violated or are about to be violated. Nevertheless, a small number of midair collisions and near misses continues to occur, most of them involving aircraft not under positive control. At the present level of traffic, the probability of collision is very low, but as traffic density increases, so does the threat of collision. The few accidents suffered by commercial carriers have heightened public awareness of the consequences of a midair collision involving large passenger aircraft. This common concern has led to significant public and private efforts to develop collision avoidance systems that would give the aircrew direct warning of the threat of collision.

A collision avoidance system is conceived as a last-resort measure to protect against collisions; it would come into play only after all other means to ensure separation have failed. A collision avoidance system is not intended to be the primary method of ensuring the separation of aircraft. But the extra margin of safety provided by a collision avoidance system could lead to changes in ATC procedures for separation assurance. For example, a reliable collision avoidance system could justify a reduction in separation standards, thus effectively increasing the capacity of the airway and airport system. This section discusses some of the alternative collision avoidance systems that have been proposed over the years in order to give the reader an awareness of their relative merits and implications.

In general, two major classes of collision avoidance systems have been proposed: those that depend on ground facilities; and those that require only airborne equipment. Ground-based collision avoidance systems characteristically require the expenditure of Government funds for facilities and equipment, while airborne systems do not. Some of the so-called airborne systems, however, are in fact passive users of ATC equipment—that is, they "eavesdrop" on replies to ATCRBS interrogations from ground surveillance stations in order to obtain the data needed to locate nearby aircraft. Some systems would be effective only when a large portion of the aircraft in the fleet are equipped, while others would provide some protection regardless of the number of users who install the equipment.

Beacon Collision Avoidance System

The Beacon Collision Avoidance System (BCAS) is one that had been under development by FAA for some time and was nearing the point of implementation when FAA made the decision, in the summer of 1981, to adopt another system that is a derivation of BCAS (see below). The initial version of BCAS, known as Active BCAS, would have been implemented first; and Full BCAS, a more complex version designed to operate in congested airspace, would have followed several years later.

In operation, Active BCAS on board aircraft would emit interrogation pulses to which ATCRBS and Mode S transponders on the other aircraft would reply in the same manner as they would reply to an interrogation from a ground station. The BCAS concept offered immediate protection against aircraft equipped with Mode C ATCRBS transponders and altitude encoders and promised more efficient performance and broader protection against aircraft equipped with Mode S Transponders. The BCAS system used the elapsed time between interrogation and reply to determine the range to other aircraft, and by calculating the rate of closure it determined the potential for collision. If a collision threat were detected, an indicator would advise the pilot whether to climb or descend to resolve the conflict. The DABS data link was to be used to coordinate the maneuvers of two BCAS-equipped aircraft. Active BCAS did not, however, provide the pilot with the relative bearing of the intruder aircraft.* Full BCAS, in addition to originating interrogations, also gathered data by listening to replies to interrogations from the ground and correlated these replies to determine bearing as well as range.

There was little question that BCAS would be effective in low-density airspace, but there was considerable concern that the system would become saturated in areas of high-traffic density where a collision avoidance system is most needed. For this reason, FAA planned to install ground equipment (an RBX transmitter) to suppress BCAS and prevent system saturation in areas of high-traffic density where it planned to rely instead on a ground-based system called the Automatic Traffic Advisory and Resolution Service (ATARS) to resolve conflicts. ATARS would use ATCRBS and Mode S interrogations and replies to gather traffic data and convey traffic information to suitably equipped aircraft by means of the Mode S data link; ATARS was designed to provide a turning manuever as well as the climb or descend maneuver of BCAS.

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*A proposed follow-on version of Active BCAS would have provided direction-finding capability.

While ATARS would overcome the major weakness of BCAS, however, it would also require considerable expenditure for both ground and airborne equipment. Both BCAS and ATARS planned to use the Mode S transponder as a key element, and both therefore were caught in the debate that surrounded the Mode S data link concept. Some critics have claimed that Full BCAS would be required to support a cockpit display of traffic information (CDTI), since the simpler Active BCAS provided no intruder bearing and thus could not provide the aircrew with a picture of surrounding traffic analogous to that available to ground controllers. In many cases it was difficult to separate the arguments for and against DABS from those pertaining to a collision avoidance system.

Tri-Modal BCAS

Tri-Modal BCAS was one proposed alternative to the BCAS program. It was similar to BCAS in concept but based on the existing ATCRBS transponder rather than the new Mode S capability, and it would operate in three different modes. In areas of high traffic density, Tri-Modal BCAS would operate passively, generating all of the required information by analyzing standard ATCRBS transponder replies to interrogations from ground surveillance stations. In areas without coverage by ground radar, it would operate like Active BCAS. Where coverage was provided by only one ground radar station, it would operate in a semiactive mode to generate its own interrogations while also listening to replies to interrogations from the ground station. The logic used by Tri-Modal BCAS would enable it to determine both range and bearing in airspace adequately covered by ground interrogators and, thus, to generate the data needed to support a CDTI.

Advocates of Tri-Modal BCAS cited the following advantages of this system:

- It does not require the Mode S transponder and provides full protection from all aircraft equipped only with a standard ATCRBS transponder.
- In airspace where the geometry of the distribution of ground-based interrogators is appropriate, it provides bearing without requiring the directional antenna that is needed for TCAS (discussed next) and Full BCAS.
- It requires no change to the ground facilities except for the activation of the north pulse on the secondary surveillance radars now installed.
- It can operate independently of all ground facilities in the same manner as active BCAS.

NASA, with the sponsorship of FAA, successfully tested Tri-Modal BCAS, but its report indicated that the tests were not exhaustive because a working model that included all of the features of the system was not available. However, the developers of the system have continued their work since the NASA tests and claim that their system is ready for certification and operational use.

Traffic Alert and Collision Avoidance System

After supporting the development of BCAS for several years, FAA announced in the summer of 1981 its decision to adopt an enhanced air-to-air version of BCAS, the Traffic Alert and Collision Avoidance System (TCAS). The abruptness of this change has led to controversy in the aviation community, and various observers have questioned both the suitability of TCAS and its superiority to alternative systems.

TCAS is a direct derivative of BCAS and is designed to meet the following criteria:

- It does not require ground-based equipment.
- It is compatible with the present ATC system and a logical extension of it.
- It is more suitable for use in high-density traffic than BCAS.
- It offers a range of capabilities suitable to the needs of various classes of airspace users.

To meet the last criterion, two versions of TCAS have been specified: both include the Mode S data link as an integral component.

TCAS I is designed for use by general aviation and the basic system is estimated by FAA to cost in the range of $2,500 to $3,500 per aircraft. TCAS I would indicate to the pilot the presence of a transponder-equipped aircraft without providing either range or bearing information; it would be the responsibility of the pilot to locate the intruder by visual means and to take the appropriate action. An upgraded version of this basic system would provide the pilot with intruder range and bearing and with information describing the maneuver that a TCAS II-equipped aircraft intended to execute. TCAS I estimates range by the strength of the signal received from another aircraft, at best an imprecise measure, and in high-density airspace the proximity-warning indicator tends to be triggered repeatedly, thus minimizing its value as a warning device (if the false alarm rate is high, pilots might tend to ignore the warning). The addition of an altitude stratifier in TCAS I, however, appears effective in minimizing high alarm rates.

TCAS II is a more sophisticated version designed for use by air carriers and larger corporate GA aircraft. FAA estimates that the necessary avionics will cost on the order of $45,000 to $50,000 per aircraft, slightly more than the projected cost of an Active BCAS unit. TCAS II operates in the same way as Active BCAS, but with two major enhancements:

- A directional send-receive antenna that will provide both range and bearing without creating the interference in areas of high traffic density expected with Active BCAS.
- The ability to transmit to TCAS I and other TCAS II aircraft information regarding its relative location and the intended maneuver to resolve a conflict.

Initially, the TCAS II antenna will provide bearing information accurate to within 30°, sufficient to provide the pilot with an "o'clock" indication of relative bearing and activate a climb or descend indicator. In later versions, FAA plans to specify an antenna with much higher angular resolution (1° to 2°), which would permit the system to generate a command for a horizontal as well as a vertical maneuver. The improved version would also support a CDTI.

FAA has issued a contract for the development of the high resolution antenna to determine if or when an antenna with this degree of resolution, yet suitable for installation on commercial aircraft, can be designed and tested. One early version of the sector scan TCAS II antenna was approximately 18 inches in diameter and extend slightly above the fuselage contour. Mounting such an antenna might require significant modifications of aircraft structure even on a large aircraft; the problem would be more severe in the case of small GA or tactical military aircraft. Further, if a large antenna were to result from the development efforts, it could have detrimental effects on aerodynamics, aircraft performance, and fuel consumption.

The adoption of TCAS means that the DABS transponder remains a key element in FAA plans. However, the fact that TCAS is ground-independent and capable of operating in airspace with high-traffic density puts in question the need for ATARS, one of the key applications heretofore envisioned for DABS. There are strong indications that FAA will drop ATARS from its plans and that, as a result, the level of expenditures on ground equipment will be significantly less than they would have been had the ATARS program been implemented.

FAA has also made a point of leaving the way open for entrepreneurial innovation in the development of TCAS. Thus, it is conceivable that FAA might certify other collision avoidance systems if their capabilities were demonstrated and if they would not interfere with TCAS or other elements of the ATC system.

For instance, TCAS and Tri-Modal BCAS could operate in the same environment because both depend primarily on responses from airborne equipment and neither requires the installation of equipment on the ground. However, as noted above, the TCAS concept contains a provision for coordinating conflict-resolution maneuvers of TCAS-equipped aircraft. Such coordination would not be possible between an aircraft equipped with TCAS and one equipped with Tri-Modal BCAS as these systems are presently designed. On the other hand, the TCAS concept does not assume that it will always be possible to coordinate the maneuvers of aircraft in a conflict situation. Therefore, the inability to coordinate the maneuvers of TCAS and Tri-Modal BCAS aircraft does not present an insurmountable barrier to operation of the two systems in the same environment.

Airborne Collision Avoidance System

All of the alternative collision avoidance systems that have been discussed to this point are capable of providing users some level of protection from aircraft that are not similarly equipped. The Airborne Collision Avoidance System (ACAS), which was developed and demonstrated in the 1970's, was not based on the ATCRBS transponder and could have been made available for about $1,500 per aircraft (1977 dollars), considerably less than the alternatives being considered at that time. A major drawback of this system, however, was that it would not be effective unless a substantial portion of the aircraft operating in a given area were ACAS-equipped.

Conceptually, the operation of the ACAS system was simple. It generated interrogations to which all aircraft within a specified altitude band would respond. Range was determined from the delay between interrogation and reply, and when an aircraft was detected at close range, subsequent interrogations narrowed the altitude band from which a reply was requested in order to determine whether a detected aircraft presented a threat of collision.

ACAS is no longer being actively considered as an alternative collision avoidance system, but it is presented here to illustrate another group of alternatives that have been explored in the past.

Microwave Landing System

Instrument Landing System

Providing precise and reliable guidance for approach and landing in conditions of reduced visibility is a prime consideration for safety of flight, but it also has important implications for the efficient use of terminal area airspace and airport runways. Generally, the highest runway utilization rates are achieved under VFR. When restricted visibility or weather conditions dictate increased separation and the use of instrument approaches, one consequence is a reduction in the number of aircraft that can be landed in a given space of time.

In part, this reduction in airport capacity utilization is a result of the guidance system in use. The present Instrument Landing System (ILS), which has been the standard U.S. system since 1941, provides guidance along a straight path at a fixed slope of 3° or less extending 5 to 7 miles from the runway threshold. All aircraft approaching the airport must merge to follow this path in single file, spaced at intervals dictated by separation minima and the need to avoid wake vortex. Aircraft flying at different speeds along this single fixed path complicate the controllers task in achieving a uniform rate of traffic flow and diminish the capability to use the full capacity of the runway served by ILS.

The runway utilization rate under IFR could come closer to that attainable under VFR if aircraft could be permitted to follow multiple approach paths, descend at different flight angles, fly at different approach speeds, or aim at different touchdown points on the runway—none of which can be done with ILS. If these variations were possible, as they are under VFR, the IFR capacity of the airport would be increased to a limit determined almost solely by the rate at which successive aircraft could touch down, decelerate, and clear the runway.*

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*Wake vortex, for example, would remain a constraint on capacity even if MLS with curved and variable glide slope approaches were installed.

Table 7.—Summary of Functional Characteristics of Alternative Collision Avoidance Systems

A/C #1 → A/C #2 ↓	ATCRBS	ATCRBS ALT ENC	DABS	TCAS I**	TCAS II	BCAS* Active
ATCRBS	None None	None None	None None	Proximity from SSR response for aircraft in radar coverage (bearing) None	Range, range rate, bearing traffic advisory None	Range, range rate, bearing traffic advisory None
ATCRBS ALT ENC	None None	None None	None None	Proximity from SSR response for aircraft in radar coverage, some altitude filtering (bearing) None	Range, range rate, bearing altitude traffic and collision avoidance advisories None	Range, range rate, bearing altitude traffic and collision avoidance advisories None
DABS	None None	None None	None None	Proximity from DABS response and from squitter altitude filtering (bearing) None	Range, range rate, bearing altitude traffic and collision avoidance advisories None	Range, range rate, bearing altitude traffic and collision avoidance advisories None
TCAS I**	None * Proximity from SSR response for aircraft in radar coverage (bearing)	None * Proximity from SSR response, some altitude filtering for aircraft in radar coverage (bearing)	None Proximity from DABS response and squitter altitude filtering (bearing)	* Proximity from DABS response and squitter altitude filtering (bearing) * Proximity from DABS response and squitter altitude filtering (bearing)	Range, range rate, bearing altitude traffic and collision avoidance advisories * Traffic advisory and above below information from TCAS II	Range, range rate, bearing altitude traffic and collision avoidance advisories Proximity from SSR response and from squitter altitude filtering (bearing)
TCAS II	None * Range, range rate, bearing traffic advisory	None * Range, range rate, bearing altitude traffic and collision avoidance advisories	None Range, range rate (bearing) altitude traffic and collision avoidance advisories	* Traffic advisory and above below information from TCAS II * Range, range rate (bearing) altitude traffic and collision avoidance advisories	* Range, range rate bearing altitude traffic and coordinated collision avoidance advisories * Range, range rate (bearing) altitude traffic and coordinated collision avoidance advisories	Range, range rate bearing altitude traffic and coordinated collision avoidance advisories Range, range rate bearing altitude traffic and coordinated collision avoidance advisories
BCAS* Active	None None	None Range, range rate bearing altitude traffic and collision avoidance advisories	None Range, range rate (bearing) altitude traffic and collision avoidance advisories	* Proximity from SSR response and from squitter altitude filtering (bearing) * Range, range rate (bearing) altitude traffic and collision avoidance advisories	Range, range rate, bearing altitude traffic and coordinated collision avoidance advisories Range, range rate (bearing) altitude traffic and coordinated collision avoidance advisories	Range, range rate, bearing altitude traffic and coordinated collision avoidance advisories Range, range rate (bearing) altitude traffic and coordinated collision avoidance advisories

*Performance degradation in high density traffic areas.

**Bearing information with optional direction finding antenna provides limited traffic advisories for TCAS I (no range or range rate) and full traffic advisories for active BCAS.

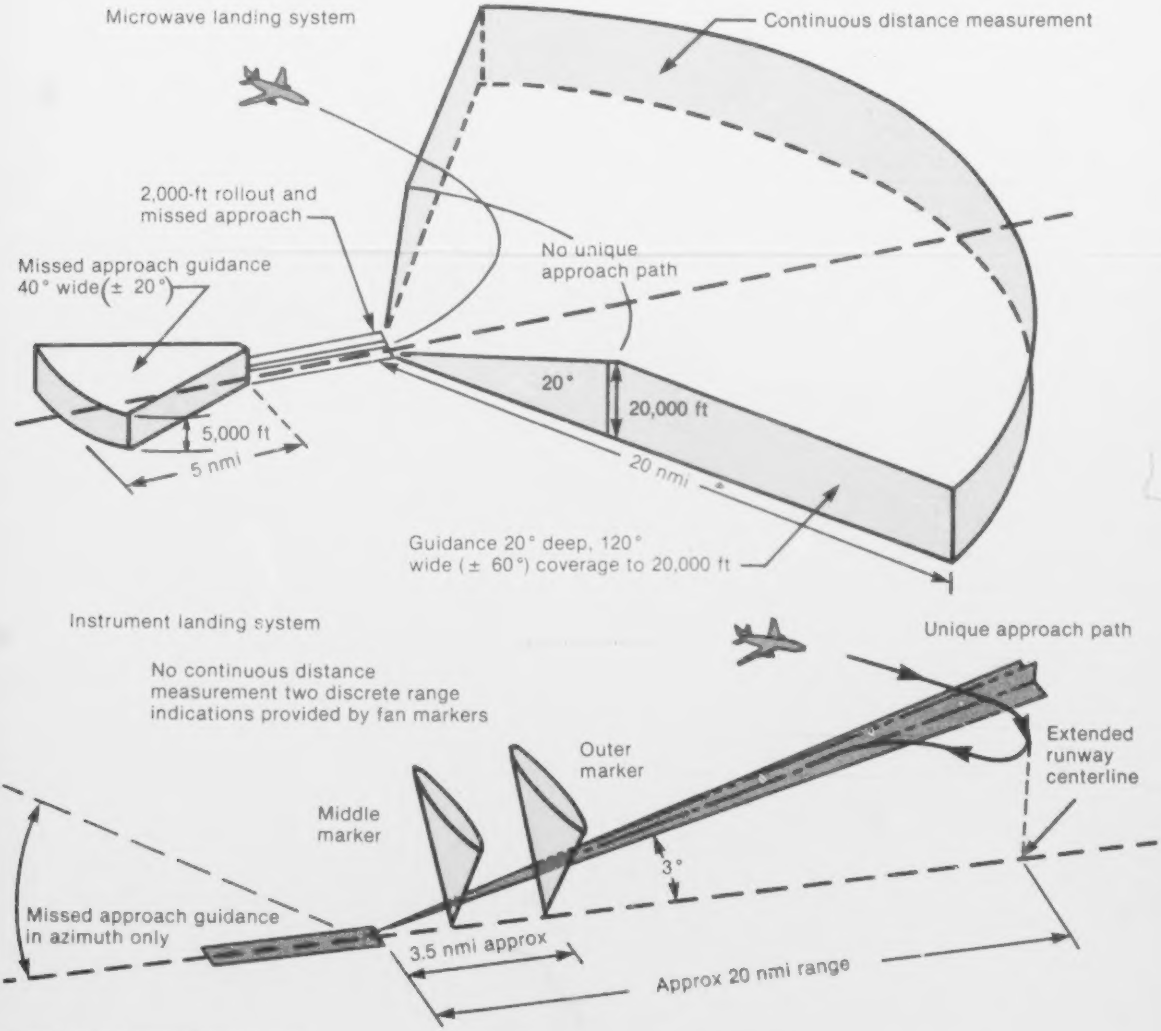
SOURCE: A. Scott Crossfield.

Microwave Landing System

A precision approach and landing system that overcomes these inherent disadvantages of ILS is the Microwave Landing System (MLS). Because MLS uses a scanning beam, rather than a fixed beam like ILS, it allows aircraft to fly any of several approach angles (including two-step glide slopes) and, in the lateral plane, to approach along complex paths that intersect the alinement of the runway at any selected point (see fig. 25). This capability is useful in avoiding noise-sensitive areas on approach paths and reducing the impact of the wake vortex problem.

MLS offers other important advantages in comparison with ILS. The reliability of the MLS signal is not influenced by ground-plane effects (snow buildup, soil moisture, tidal effects, etc.); this permits MLS to be installed at sites where ILS will not function properly. Fixed or moving obstacles in the approach zone do not interfere

Figure 25.—Comparison of Microwave Landing System and Instrument Landing System


Microwave landing system
Continuous distance measurement
2,000-ft rollout and missed approach
No unique approach path
Missed approach guidance 40° wide (± 20°)
20°
20,000 ft
5,000 ft
5 nmi
20 nmi
Guidance 20° deep, 120° wide (± 60°) coverage to 20,000 ft
Instrument landing system
Unique approach path
No continuous distance measurement two discrete range indications provided by fan markers
Outer marker
Middle marker
Extended runway centerline
3°
Missed approach guidance in azimuth only
3.5 nmi approx
Approx 20 nmi range

SOURCE: Federal Aviation Administration.

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with MLS signals to the same degree as with ILS. In addition, MLS also provides precision guidance for departures and missed approaches, a feature of particular importance when traffic patterns of closely located airports are in conflict. MLS operates in a frequency band that provides 200 transmission channels; ILS has used only 20 of the 40 channels theoretically available to it, and these are very near saturation in large hubs such as New York and Los Angeles. Finally, ILS does not meet the joint civil/military operational requirement for precision approach, since it does not afford the tactical flexibility needed by military aircraft. MLS does.

For these reasons, FAA has designated MLS as the precision approach guidance system to replace ILS. The MLS transition plan, published by FAA in 1981,[12] calls for 1,425 installations to be carried out in three phases over the next 20 years. In the first phase, between 10 and 25 systems will be installed over a period of 2 years at selected airports in order to develop a base of experience and reach an operational confirmation of the benefits that MLS can provide. The second phase will see the installation of 900 additional MLS units at a rate of 100 to 150 per year over a period of 6 to 9 years, with priority given to large and medium hub airports. The third phase involves installation of an additional 300 to 500 units to meet the growth in demand anticipated by the end of this century. FAA estimates the cost of purchasing and installing 1,425 MLS ground units to be $1.332 billion (1981 dollars); the cost to users to equip their aircraft with MLS is estimated to be an additional $895 million, yielding a total cost of roughly $2.2 billion.[13]

In selecting the transition plan, FAA worked in consultation with various user groups under the auspices of Radio Technical Commission for Aeronautics, and considered 10 deployment strategies—9 submitted by FAA and 1 developed by RTCA Special Committee 125. These strategies differed in terms of the order and rate of deployment at various sites, the length of the period of duplicative operation with ILS, and assumed rates of user equipage. Each strategy was analyzed to estimate costs, benefits, and operational effects. All strategies yielded favorable net benefits in the range of $2.4 billion to $2.7 billion. The costs of the 10 strategies varied narrowly ($1.20 billion to $1.35 billion for ground units), as did the benefits ($3.65 billion to $4.05 billion). These results led FAA to conclude that "there is no clear-cut economic rationale for choosing among the MLS implementation strategies" and that "the choice should be based upon operational considerations or on the special opportunities for improved precision guidance service created by the installation of MLS equipment."[14] The strategy selected by FAA reflects these considerations.

Potential Implications and Issues

There are two factors that may complicate the MLS transition plan, both of them involving the replacement of the existing ILS. As of March 1981 there were 653 ILS units in commission at 458 airports, and an additional 155 units were in various stages of procurement or installation. Thus, the MLS transition plan has to take into account how these ILS sites, many of them recently commissioned and with many years of service life remaining, are to be phased out. ILS and MLS can be colocated and operated simultaneously without signal interference or procedural difficulty, but the length of the period of joint operation and the timing of ILS decommission at specific sites could create difficulties for some classes of airport users. FAA transition plan stipulates that no ILS will be removed until all of the network's ILS-equipped airports have operational MLS and at least 60 percent of the equipped aircraft routinely using the ILS/MLS runway are MLS-equipped. When this occurs however, 40 percent of the regular users of a given airport could lose the precision-landing service, even though they continue to operate with functioning ILS equipment.

The second complication is that, by ICAO agreement, the United States is committed to retain ILS service at international gateway airports through 1995. There are 75 such airports at present, and generally they are among the busiest U.S. airports. The retention of ILS service at these sites may cause some users to delay purchasing MLS equipment, since the installed ILS equipment will still be usable for another 10 years or more.

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[12] *Microwave Landing System: Transition Plan*, APO-81-1 (Washington, D.C.: Federal Aviation Administration, May 1981).

[13] Ibid.

[14] *Microwave Landing System Transition Plan*, op. cit.

Despite the overall favorable benefit-cost ratio of MLS indicated by FAA analysis, the specific benefits and costs to various classes of airspace users remains a subject of controversy. FAA's analysis showed high positive net benefits to air carriers and commuters largely due to the value attributed to passenger time saved. For general aviation as a whole, the costs exceeded the benefits for all 10 deployment strategies, although some classes of GA (notably corporate GA operating multiengine piston and jet aircraft) were shown to derive substantial benefits from MLS. Thus, there is likely to be continued resistance to MLS from some GA operators, probably in the form of opposition to decommissioning ILS at specific sites and reluctance to purchase MLS equipment (at a cost of $5,000 or more) so long as ILS is available.

It is also likely that specific details of the MLS transition plan will continue to arouse debate. Comment received by the FAA during the course of preparing the plan indicates that there are several sensitive points. One potential issue is the priority given to installation of MLS at different types of airports. For example, commuter airlines favor early deployment at small community airports, while the Airline Pilots Association seeks to have MLS first installed at hub airports on runways not now ILS-equipped. Other user groups, for example the Air Transport Association, recommend an installation strategy that would create a network connecting major airports (including many now equipped with ILS), in order to encourage users who fly these routes frequently to install MLS equipment on their aircraft. Another, slightly different, recommendation would involve establishment of a major-city network but with priority also given to installation at sites where it is not possible to locate an ILS and at small community airports that have commercial service but not an ILS.

AS a final point, the MLS transition plan proposed by FAA may encounter administrative and budgetary difficulties. The plan, particularly Phase II, is highly ambitious in that it calls for installation of 900 units at a rate of 100 to 150 per year. It may be technically and administratively difficult to sustain such a pace, and it might be even more difficult to justify the required annual outlay of funds in a time of budget austerity. Implementation of Phase II would entail annual expenditures of $125 million on a 6-year schedule, or $85 million on a 9-year schedule. Stretching out Phase II, in order to hold it within some imposed budgetary limit, is an alternative that may have to be adopted, even though it might increase overall program costs and defer realization of the full benefits of MLS.

ALTERNATIVE ATC PROCESSES

FAA is nearing the end of research and development of several major components of the ATC system and is about to begin operational deployment of these new technologies. Most of the system improvements planned by FAA would continue the present trend toward a ground-based, centralized control system with increasingly more extensive requirements for avionics and more restricted forms of operation. These plans would also entail a major commitment of funds by the Federal Government and the aviation community. It is important that the Congress be satisfied, not only as to the soundness and appropriateness of these prospective system changes, but also as to whether FAA's plans take into account the new alternatives that are being made available by emerging technologies.

There are five aspects of the future ATC system on which new technologies might have an especially important influence in creating new options:

- the role of the human operator;

- tactical v. strategic control;
- autonomy and flexibility of control;
- ground v. satellite basing; and
- levels of service.

Role of the Human Operator

The AERA concept implies that computers will assume many of the controller's routine decisionmaking tasks and, by means of digital data link, many of the communications tasks as well. The immediate consequences would be that fewer human operators would be needed to handle a given volume of traffic and that the human role would evolve toward that of a manager of automated resources.

However, there would also be important consequences for the pilot. The increased level of automation on the ground would bring a corresponding increase in opportunities to employ automation in the cockpit. Aircrew dependency on airborne data processors and displays would increase as more information would be transmitted digitally and the relative importance of the voice channel waned.

Another consequence of automation is that the burden of responsibility for operational reliability would shift. Safety would be assured more and more through the design process and less through the compensatory actions of the human operator.

Tactical v. Strategic Control

A system supported by powerful data processors can collect, analyze, and distribute information on a much wider scale than the present ATC system. This makes it possible to plan and coordinate the movement of traffic over a broader area and a longer span of time. The basic mode of control could therefore become more strategic and anticipatory—relying more on prevention of conflict through planning, and less on tactical or reactive response to actual or imminent violations of separation minima.

For the ground controller, whether human or computer, the principal task would be monitoring aircraft movements to ascertain conformance with a flight plan that, through planning, had been determined to be conflict-free. For the pilot (aided by a flight management computer and onboard ATC systems), the principal task would be to fly from origin to destination without deviating from that flight plan unless unforeseen circumstances (such as weather or deviations of other aircraft) forced rerouting. Tactical control measures would still be available, but they would be called into play only when strategic measures proved inadequate to forestall conflict.

Autonomy and Flexibility of Operation

IFR control is now centralized on the ground because only the ground controller has the information needed to assure separation and an orderly flow of traffic. However, improvements in communication and processing technologies have made it possible to redistribute information among the various participants in the ATC system.

Given greater access to information, aircrew could become more active participants in the ATC process. As the quality and timeliness of the information improves, interaction with ground controllers could become infrequent. However, there is a logical limit to their independence from ground control, because overall strategic control of the flow of traffic will remain a ground-based function.

Ground v. Satellite Basing

Navigation and surveillance functions in the present system are ground-based, as are the facilities for relay of air/ground radio transmissions. The development of space technology makes it possible to consider satellites as alternatives for all three purposes. Satellites could be used in either an active or a passive mode. In the passive mode, they could serve as relay stations for communication between the air and the ground or between ground sites where present methods are limited to line of sight. Satellite-mounted transponders could also provide position reference for airborne navigation systems. In an active mode, data processing capabilities could be installed in satellites to track aircraft and report their location to ground-based control facilities, either replacing or supplementing surveillance radar.

Levels of Service

Under the present ATC system there are only two forms of operation—controlled (corresponding roughly to IFR) and uncontrolled (corresponding roughly to VFR). In the future, improvements in ground-based and airborne technologies could make it possible to provide intermediate levels of ATC services between these two extremes. The level of service could vary according to 1) the density of traffic; 2) the mix of aircraft; 3) the avionics carried by those aircraft; 4) flight conditions; and 5) the ground-based capability for separation assurance and traffic management. The result could be a more varied range of services, more closely tailored to the needs and capabilities of the airspace users, than is now the case.

Chapter 6

AIRPORT CAPACITY ALTERNATIVES

Photo credit: Federal Aviation Administration

Dulles International

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Chapter 6

AIRPORT CAPACITY ALTERNATIVES

INTRODUCTION

The ability of airports to accommodate traffic can be expressed in terms of "airside" or "landside" capacity. "Airside" capacity is defined here as the number of air operations—landings and takeoffs—that the airport and the supporting air traffic control (ATC) system can accommodate in a unit of time, such as an hour. The capacity of an airport is not a single number, but will vary with the number of runways in use, the visual or electronic landing aids available, the types of aircraft being accommodated, the distance between aircraft in the approach pattern, and the noise abatement procedures in effect. The time each aircraft occupies the runway and the facilities for handling aircraft on the ground, on taxiways, or at gates also affect airside capacity. All of these factors will vary depending on the weather.

"Landside" considerations, such as the size and number of lounges or the adequacy of baggage-handling equipment, affect the number of passengers an airport terminal can accommodate. Ground access, including the adequacy of transit connections, roadways, and parking areas for passengers' cars, is an important part of an airport's landside capacity, and in some cases has become a limiting factor on an airport's ability to handle passengers. Recent discussion about putting a quota on operations at Los Angeles International Airport, for example, is related to growing ground access problems, not lack of airside capacity.

This chapter discusses alternatives to increase airport *airside* capacity. Landside problems will only be treated here as they affect airside capacity.

When the traffic demand for an airport approaches or exceeds its capability, the result is delay. Delay has been a major problem at the Nation's busiest airports, resulting in millions of dollars of increased operating costs for air carriers and wasted time for travelers. Although several different methods of measuring delay exist (as will be discussed later) it is generally agreed that the six airports most affected by delay in 1980 were: O'Hare (Chicago), Stapleton (Denver), La Guardia and JFK (New York), Hartsfield (Atlanta), and Logan (Boston). As shown in table 8, most of the airports which report

Table 8.—"Top" U.S. Airports, by Enplaned Passengers, by Air Carrier Operations, and by Reported Delays

Passenger enplanements	Air carrier operations	Delays over 30 minutes
1. Chicago O'Hare	Chicago O'Hare	Chicago O'Hare
2. Atlanta Hartsfield	Atlanta Hartsfield	Denver Stapleton
3. Los Angeles International	Los Angeles International	New York La Guardia
4. New York J.F. Kennedy	Dallas-Ft. Worth	New York Kennedy
5. San Francisco International	Denver Stapleton	Atlanta Hartsfield
6. Dallas-Ft. Worth	Miami International	Boston Logan
7. Denver Stapleton	San Francisco International	Los Angeles International
8. New York La Guardia	New York La Guardia	St. Louis Lambert
9. Miami International	New York J.F. Kennedy	San Francisco International
10. Boston Logan	Boston Logan	Dallas-Ft. Worth
11. Honolulu International	Washington National	Philadelphia International
12. Washington National	St. Louis Lambert	Newark
13. Detroit Metro	Detroit Metro	Washington National
14. Houston Intercontinental	Houston Intercontinental	Miami International
15. St. Louis Lambert	Honolulu	

SOURCE: *Federal Aviation Administration, Terminal Area Forecasts, Fiscal Years 1981-92*, Washington, D.C.: 1981 p. 13; Interview, FAA, *Air Traffic and Airways Facilities*, Aug. 20, 1981.

serious delay problems rank among the top 15 airports in terms of both enplaned passengers and air carrier operations.

This chapter first describes the airside components in the operation of a typical airport. It then reviews those major factors which influence or limit airside capacity. Next the chapter discusses the problem of delay—how it comes about and the methods for measuring it and estimating its costs. The next sections outline some alternative methods for reducing delay or increasing the airside capacity. These include changing the pattern of traffic demand, expanding the runway system, or modifying the terminal area air traffic control procedures and equipment. Finally, some suggestions for future research are made.

AIRSIDE COMPONENTS

The airside capacity of an airport is governed by factors related to its runway system and the airspace above and around the airport, as well as the terminal area ATC and navigation equipment and procedures.

The number of runways, their layout, length, and strength will in large measure determine the kinds of aircraft that can use the airport and how many aircraft can be accommodated in any given time period. The layout depends on a number of factors including the local terrain and predominant direction of the wind. Federal Aviation Administration (FAA) safety regulations dictate how close the runways may be to one another and to buildings, trees, or other obstructions.

In order to land on a runway, aircraft approach the runway in single file, with a safe distance between them. Air traffic may enter the airspace around the airport ("terminal area") from many directions at a number of different points ("entry fixes"), and in many metropolitan areas the aircraft may be destined for one of several different airports. Thus, the task of delivering aircraft one by one to a particular runway at a particular airport must begin many miles from the airport itself, and controllers must orchestrate the orderly merging and diverging of many different traffic streams until each aircraft reaches the final approach to its destination runway. By the same token, departing aircraft must be safely routed from the airport to the "departure fix" where they leave the terminal area and join the en route ATC system.

Controllers use both vertical and horizontal separation to maintain safe distances between aircraft, a task that is complicated by their different performance characteristics. Jets flying at a very slow (for a jet) 160 knots will nevertheless overtake and pass slower aircraft. The controller may assign different altitudes so that this can take place safely, or he may vector the faster aircraft along a longer path so that it will safely overtake and pass around the one ahead.

In good visibility conditions, tower controllers may clear aircraft, once they are in sight of the airport, to make a visual landing under tower control. The pilot assumes responsibility for separating himself from other aircraft, with the controller standing by to warn pilots to "go around" in case of a potential conflict. During times of poor visibility the ATC team retains responsibility for separating the aircraft on final approach. In this case the Instrument Flight Rule (IFR) radar minimum separation is observed, so

Photo credit: Neal Callahan

The variety of airspace system users

that distances between aircraft are greater than in good weather. Under IFR conditions, pilots are much more dependent on landing aids such as the Instrument Landing System (ILS) to guide them to the runway.

An aircraft is considered to be on the runway from the moment it flies over the runway threshold until it turns off onto a taxiway. Angled "high-speed" turnoffs can allow aircraft to leave the runway at higher speeds than perpendicular ones. Placing the turnoffs where they will be convenient to most of the aircraft using a runway is important for getting maximum capacity from the runway system.

Departures from the airport may take place on a separate runway or may be "interleaved" between arrivals on the same runway. Aircraft preparing to depart can wait beside the runway on holding aprons until the runway is clear; then they can then taxi onto the runway and take off fairly quickly—the time spent on the runway for departure is on the order of 30 seconds.

LIMITATIONS ON AIRSIDE CAPACITY

Among the major factors influencing airport capacity are: aircraft performance characteristics, wake vortex turbulence, weather, airfield and airspace configuration, aircraft noise, ATC equipment and procedures, and demand considerations.

Aircraft Performance Characteristics

Characteristics of the aircraft—their size, aerodynamics, propulsion and braking performance, and avionics—will affect the capacity of the runways they use. Pilot training, experience, and skill will also influence performance, and the capacity of a runway can vary greatly with the types of aircraft using it. Runway capacity is usually highest if the "traffic mix" is uniformly small, slow, propeller-driven aircraft. The next highest capacity would come with a uniform mix of large jets. Where the traffic mix is highly diverse—with jet and propeller aircraft of widely varying sizes and speeds—it is usually difficult to maintain optimum spacing and optimum runway usage, and runway capacity is reduced. The direction of traffic also affects runway system capacity. When arrivals predominate, capacity is lower then when departures predominate.

Wake Vortex

Related to aircraft performance characteristics is the problem of wake vortexes. Aircraft passing through the air generate coherent energetic air movements in their wakes, and under quiescent weather conditions the wake vortex can persist for 2 minutes or even longer after an aircraft has passed. The strength of the vortex increases with the weight of the aircraft generating it. As the use of wide-bodied jets (e.g., B-747 and DC-10) became more common in the early 1970's, it became apparent that wake vortexes behind these heavy aircraft were strong enough to endanger the following aircraft, especially if it was smaller. Until the potential danger of wake vortex to transport sized aircraft was demonstrated (e.g., the 1972 crash of a DC-9 landing in the wake of a DC-10) standard separations of 3 nautical miles (nmi) were required under IFR conditions. In order to prevent accidents caused by wake vortexes, FAA increased the separations for smaller aircraft behind larger ones during weather conditions when persistent vortexes may be a danger. These minimums are shown on the right side of table 9.

Weather

Heavy fog, snow, strong winds, or icy runway surfaces reduce an airport's ability to accommodate aircraft and may even close an airport completely. For a given set of weather conditions, several of the different runway configurations available at an airport may be suitable but only one will have the maximum value. Using these maximum values, and plotting them with the percentage of the year during which different weather conditions are likely to prevail, a

Table 9.—Arrival and Departure Separations

Minimum Arrival Separations—Nautical Miles

Visual Flight Rules*

Lead \ Trail	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

Instrument Flight Rules

Lead \ Trail	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

Minimum Departure Separations—Seconds

Visual Flight Rules*

Lead \ Trail	S	L	H
S	35	45	50
L	50	60	60
H	120	120	90

Instrument Flight Rules

Lead \ Trail	S	L	H
S	60	60	60
L	60	60	60
H	120	120	90

*VFR separations are not operational minima but rather reflect what field data show under saturated condition. Adapted from *Parameters of Future ATC Systems Relating to Airport Capacity/Delay* (Washington, D.C.: Federal Aviation Administration, June 1978), pp. 3.3, 3.5.

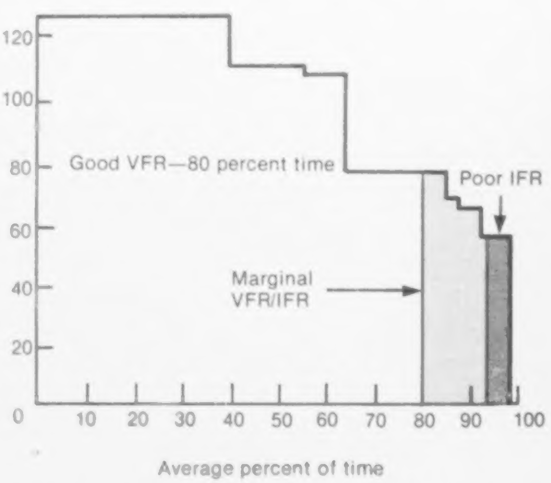
"capacity coverage curve" for any given airport can be constructed.

An example of a capacity coverage curve is shown in figure 26. The highest hourly capacity of Boston Logan Airport is 126 operations per hour in Visual Flight Rule (VFR) weather. This combination of highest capacity runway use and good weather is available 40 percent of the year. Strong winds create crosswind components which close some of the runways of that configuration, and hourly capacities continue to decrease as marginal weather and finally bad weather cause restrictions in safely operating the runway system. There is a small percentage (2 percent) of the year when poor visibility, ceilings, and snow completely close the airport. Notice that there is a wide variation in the hourly capacity from 126 operations per hour down to 55 operations per hour before the airport closes. This is typical of many major airports where several runway combinations exist. This wide variation in hourly capacity prevents the establishment of a single capacity value for the airport; instead, it will be variable depending on weather conditions.

Figure 26.—Airport Hourly Capacity Varies Strongly With Weather

(There is a 3 to 1 or 2 to 1 ratio between good weather/bad weather capacities)

Capacity Coverage Curve—Boston Logan Airport



SOURCE: Robert W. Simpson, "Airside Capacity and Delay at Major U.S. Airports," draft report prepared for the Office of Technology Assessment, U.S. Congress, Washington, D.C., October 1980.

It is difficult to foresee any capital investment in runways or technological improvements to ATC facilities which can completely eliminate this degradation of capacity with weather conditions. New runways can raise the overall level of the capacity coverage curve, but they do not

Photo credit: Federal Aviation Administration

Snow control at a terminal

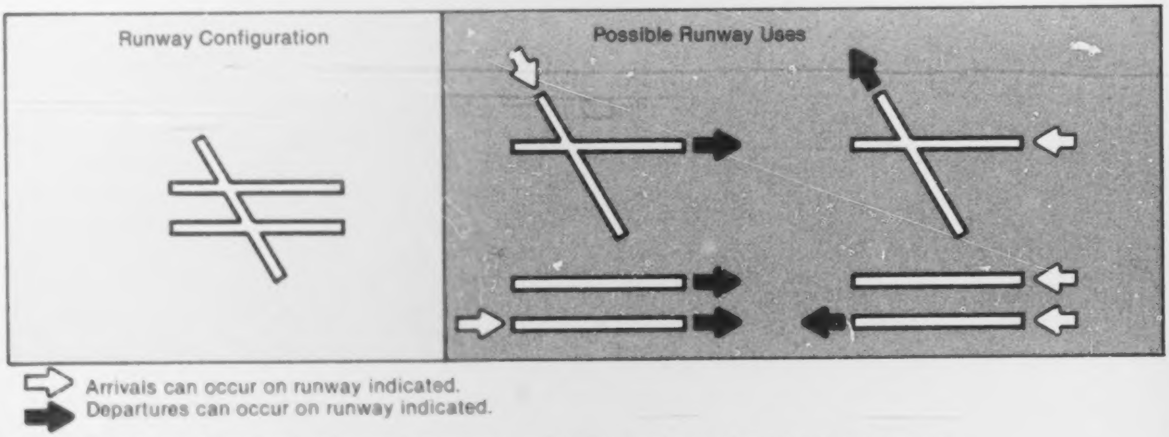
prevent its degradation with weather. Some of the ATC improvements discussed later in this chapter attempt to improve overall capacity by reducing the gap between IFR and VFR performances.

Airfield/Airspace Configuration

The capacity of an airport depends to a large extent on the number of runways available and their interactions. For example, for a given traffic mix a particular runway can handle 65 operations an hour in VFR conditions and 55 in IFR weather. The VFR capacity of two parallel runways, 2,500 ft apart, might then be 125 operations per hour—twice the capacity of a single runway. Yet the IFR capacity of this two-runway system would be more like 65 operations per hour, because under IFR conditions runways less than 4,300 ft apart are considered "dependent" for purposes of landings—that is, an operation on one prevents a simultaneous operation on the other. Similar safety restrictions apply where runways converge or intersect with one another. Thus, not only is the capacity of each runway reduced during bad weather, but the capacity of the airport is further reduced because not all runways may be fully used.

In the illustration in figure 27, the three runways could be used in several different ways, four of which are shown. Each of these combinations may have a different operating capacity, and each might be suitable for a different set of wind, visibility, and traffic conditions. A large airport like O'Hare might have 40 or 50 possible combinations of runway uses. The limitation imposed by the available runway system varies among the top air carrier airports. Chicago O'Hare has seven runways, Kennedy has five, and La Guardia has only two (La Guardia's additional short 2,000-ft runway can be used only for departures during good weather conditions). Yet the capacity relationship is not linear: La Guardia manages to handle 40 percent of O'Hare's total aircraft movements with less than 30 percent of its runways. An adequate taxiway/gate configuration is also needed in order to support optimum runway usage. For instance, the La Guardia Airport capacity task

Figure 27.—Runway Configuration


Runway Configuration
Possible Runway Uses
Arrivals can occur on runway indicated.
Departures can occur on runway indicated.

SOURCE: Federal Aviation Administration, *Techniques for Determining Airport Airside Capacity and Delay*, FAA-RD-74-124, June 1976.

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force found that additional taxiways in one area were critical to minimizing delays. This is because space at gates was limited, and the additional taxiways could be used to hold and sequence departing aircraft during periods of congestion.

Aircraft Noise

Aircraft noise, especially the noise of jet aircraft, has made airports unpopular with their neighbors. The greatest noise impact is usually in the areas just beyond the ends of the runways, where arriving and departing aircraft fly at low altitudes. If a high-noise area is occupied by a factory or a highway cloverleaf there may be little difficulty, but such land uses as residences, hospitals, and schools are not compatible with the amount of noise generated by an airport. In some areas, ineffective or nonexistent zoning and land use controls over the years have allowed these incompatible land uses to occupy high noise impact areas near many airports. The courts have generally found that the airport operator is responsible for injury due to reduced property value, and owners of nearby property have been able to collect damages in some cases. In Los Angeles, the courts have recently awarded nuisance damages as well. In some areas, including Atlanta, St. Louis, and Los Angeles, airport operators have been required to purchase noise-impacted property and either use it as a buffer zone or resell it for a more compatible use.

One method for reducing noise is to introduce quieter aircraft or, as many air carriers have begun doing, to re-equip old aircraft with quieter engines. FAA has set standards for new aircraft that are much quieter than in the past, but noisy aircraft will remain in the fleet for many years. The increasing sensitivity of the public to noise may have offset much of the recent improvement.

FAA, at the request of individual airport operators, has also developed operational procedures that reduce noise impact. For example, use of certain runways may be preferred, or pilots may be required to make approaches over less sensitive areas, weather permitting. However, FAA has established very few mandatory noise-abatement procedures. Over the past few years some operators have conducted airport noise compatibility and land use studies for use as a basis for their own noise planning. The new Federal Aviation Regulation, Part 150, required under the Aviation Safety and Noise Abatement Act of 1979 (Public Law 96-193), provides operators with guidelines for voluntary noise-abatement standards and establishes a standardized method for measuring noise exposure.

Photo credit: Federal Aviation Administration

Air use and land use

Many of these noise-control procedures have a negative effect on capacity, and airports with both capacity and noise problems have found that the available solutions to one problem often aggravate the other. The highest capacity runway configuration, for instance, may be one which requires an unacceptable number of flights over a residential area. Enforcing noise-abatement procedures may also cause an unacceptable level of delay at peak hours. Thus, airports must balance tradeoffs between usable capacity and environmental concerns.

The FAA Administrator recently reemphasized that the responsibility for establishing proper land-use controls around airports rests with local government. He also predicted that more communities will be establishing local noise limits by ordinance or statute.[1]

A local government, whether or not it is the owner of the airport, can exercise some control over noise, but must do so in a manner that is nondiscriminatory and does not place an undue burden on interstate commerce. For example, a city may select a reasonable noise exposure limit and exclude or fine aircraft exceeding that limit. However, the total ban on jet aircraft in Santa Monica, Calif., was overturned by the courts as unduly discriminatory against one class of aircraft (some new jets are quieter than propeller-driven aircraft).

ATC Equipment and Procedures

Improvements in aircraft surveillance, navigation, and communication equipment over the past decade have greatly increased the ability of pilots and controllers to maintain high capacity during all weather conditions (see ch. 5). However, there are still ATC-related limits on airport capacity. Clearances used in the en route airways and the terminal airspace are frequently circuitous, routing aircraft through intermediate "fixes" or control points rather than allowing them to travel directly from origin to destination. While this places aircraft in an orderly pattern so that controllers can better handle them, it also reduces capacity and consumes time and fuel.

The limitations in the accuracy of surveillance equipment also can influence how airports are constructed and how they may be used. For example, the spacing requirement between independent IFR runways was developed based on the limitations of surveillance, navigation, and communications equipment. Improvements in equipment and procedures have allowed this minimum to be reduced over the years.

Constraints on capacity can arise when airspace near one airport must be reserved to protect operations at another airport. This is an especially pressing problem in some busy areas. There is such an airspace conflict between La Guardia and Kennedy in certain weather conditions, for example.

Demand Considerations

The daily pattern of demand is characteristic of the airport and the travel markets it serves. Air travelers prefer to travel at certain times of the day—midmorning and late afternoon, for example—and air carriers wish to accommodate them. Heavy scheduling at peak hours makes it easier for passengers to transfer to other planes or other airlines, yet (as will be discussed shortly) peaks in demand can be major causes of delay. Even at airports with a high percentage of scheduled traffic it is not possible to predict the actual number of aircraft which will appear at a particular hour of a given day, as nonscheduled traffic volume can vary substantially. At quota airports, the quota is set at a value between the VFR and IFR capacity, resulting in a built-in delay situation whenever weather conditions deteriorate.

DELAY AND DELAY REDUCTION

Airport delays received a great deal of publicity during the late 1960's and they continue to be a major waste of time, money, and fuel. Delay can be expected whenever instantaneous traffic demand approaches or exceeds the airport's capacity. When traffic occurs in bunches or peaks, there may be delays even when the number of aircraft using the airport is less than the capacity for that peak time period. Some amount of delay arises every time two aircraft are scheduled to use a runway at the same time. The probability of simultaneous arrivals increases rapidly with traffic density, so that average delay per aircraft increases exponentially well before traffic levels reach capacity levels.

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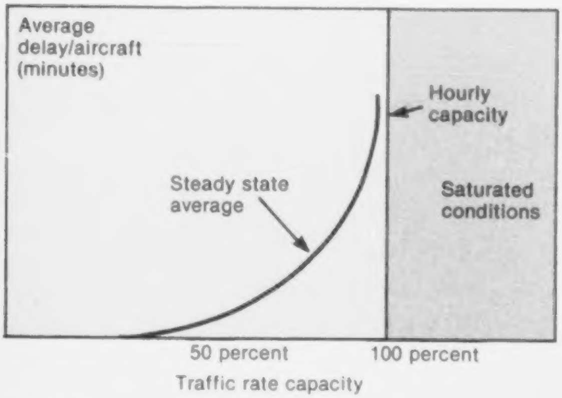
[1] "Helms Places Airport Noise Problems on Operators, Communities," *Aviation Daily* Sept. 29, 1981, p. 154.

A typical variation of delay with operation rates is shown in figure 28. When the traffic level is above capacity, the accumulation of aircraft awaiting service is directly proportional to the excess of traffic over capacity. For example, if the capacity of a runway system is 60 operations per hour and traffic rates are averaging 70 operations per hour, then every hour will add an average of 10 aircraft to the queues for service, and 10 minutes to the delay for any subsequent arrival or departure. Even if the traffic level drops to 40 operations per hour, delays will persist for some period since the queues will be depleted at a rate of only 20 aircraft per hour.

The principal delay-reporting systems of FAA currently measure only the occurrence of large delays. The National Airspace Communications System (NASCOM) delay reports record instances of delays of 30 minutes or more at 46 participating airports. The Performance Measuring System (PMS) records delays of 15 minutes or more at 15 major airports. The PMS also attempts to estimate "average delay per aircraft delayed." Both NASCOM and PMS rely on controller's manual recording of instances and causes of delays during periods when he is already busy. Weather is listed as the primary cause for these delays, ranging from 76 percent of the 30-minute delays in 1976 to 84 percent in 1979 in the NASCOM system. The total number of delays reported also increased, from approximately 36,200 in 1976 to approximately 61,600 in 1979. It must be emphasized that while weather may indeed be the primary cause, the ability of the system to anticipate, adjust to, and recover from weather-related problems is dependent on a number of the other determinants of airside capacity.

Figure 28.—Typical Distributions of Delay



SOURCE: Office of Technology Assessment

Another major delay-reporting system is sponsored by FAA and three airlines—Eastern, United, and American—which have been pooling their operational flight-time data since 1976. This Standard Air Carrier Delay Reporting System (SACDRS) covers 36 airports and measures taxi times, gate holds, and flight times against standard values in an attempt to determine delay. Unfortunately, an error in this method causes an overestimation of delay: for example, the standard times used for taxi in and out are based on the average over *all* runways at a given airport, but at some airports there is wide variation in taxi times for different runways and terminals; some percentage of these longer taxi times are always counted as delay under the SACDRS. FAA recognizes the deficiency in this system, but no correction has yet been devised. Estimates of the annual cost of delay based on SACDRS have ranged as high as 237 million gallons of fuel and $273 million of additional operating costs to the three airlines involved, although these costs too are overestimated.[2] The PMS and NASCOM systems, on the other hand, because they only count long delays, probably underestimate delay. The true value of delay lies somewhere in between and has not been determined with accuracy. Thus, estimates of the cost of delay based on any of these reporting systems have to be viewed with some caution. However, all observers agree that delay is a serious and expensive problem at some airports, especially in light of the high cost of fuel in recent years.

One method of dealing with delay is to constrain traffic to manageable levels. This is the

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[2] Virginia C. Lopez (ed.), *Airport and Airway Congestion, A Serious Threat to Safety and the Growth of Air Transportation* (Washington, D.C.: Aerospace Research Center, July 1980).

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origin of the quota systems which have been imposed at a few major airports. Each carrier has representatives on the "scheduling committees" to negotiate the carrier's share of allowed peak hour operations. FAA, through its flow control center, also works to ameliorate the costs of delays by forewarning air carriers when delay conditions develop at major airports. For example, when weather deteriorates and capacity goes down in Chicago, FAA may advise aircraft scheduled into Chicago to delay their arrival there by waiting on the ground at other cities. Waiting on the ground is much less wasteful of fuel than waiting in holding patterns in the air.

Although the lengthy delays of the late 1960's are no longer typical, delay remains a major problem at many airports. Further, the number of operations will increase as air traffic grows, and additional airports may experience this problem. Some possible approaches to dealing with delay are discussed below.

DEMAND-RELATED ALTERNATIVES

Delay problems tend to be concentrated at the Nation's major airports, and even at these locations the problem is most acute during certain hours of the day (usually midmorning and late afternoon). If operations could be shifted from these peak hours to less busy times, delay could be reduced and the overall capacity of the airport better utilized. Variable user fees or quotas during peak hours are tools which have been suggested, and tried at some locations, to reduce peak demand and increase operations in nonpeak hours. All these mechanisms, however, reduce the ease of transferring from one flight to another at hub airports, making it harder to achieve ideal airline economics.

Peak-Hour Pricing

Most airports now charge a landing fee based on the weight of the aircraft. This fee schedule is designed to recover construction and operating costs of the airport, not to ration capacity. However, when the use of an airport is nearing capacity it could be more economically efficient to base landing fees on the marginal costs imposed by each additional aircraft served. This means that the user should pay not only for use of the airport, but for the delay caused other users who want to use it at the same time. This method allows users who value access to the airport at peak times to pay for their preference; those who do not wish to pay the higher fee would use the airport at other times, or perhaps use another airport.

In general, peak-hour pricing would have little effect on air carrier operations unless the price changes are very large. Airlines schedule flights when they think passengers will want to fly, and they would probably be willing to absorb moderate increases in user fees in order to use the airport at those times. Even a landing fee of several hundred dollars would be small compared to the total operating costs of a large jetliner, and such an expense could be passed on to the passenger by a relatively small increase in fares. Commuter air carriers, with their smaller number of passengers, would be unable to pay landing fees quite as high as the larger carriers.

General aviation (GA) users on the other hand, especially student and personal flyers, are more sensitive to increases in landing fees. The Port Authority of New York and New Jersey's 1968 decision to increase minimum landing fees from $5 to $25 during peak hours brought about an immediate decline of about 30 percent in GA operations during peak hours at its three air carrier airports (JFK, La Guardia, and Newark) and a noticeable decline in aircraft delays of 30 minutes or more.[3] In 1979, a $50 surcharge added to peak-hour landing fees at Kennedy and La Guardia resulted in a further decrease in GA traffic at those airports.[4] The remaining GA users were primarily high-performance turboprop aircraft used for corporate travel; corporations, like the airlines, may be willing to absorb a fairly large increase in fees in order to use specific airports during peak hours.

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[3] *Airport Quotas and Peak Hour Pricing: Theory and Practice* (Washington, D.C.: Federal Aviation Administration, 1976), pp. 54-60.

[4] Port Authority of New York and New Jersey, Aviation Department, interview, Oct. 23, 1981.

One problem with a peak-hour pricing system is that it is difficult in practice to determine precisely what the marginal cost of an airport operation is; several years of trial and error would be necessary to settle on a pricing scheme which both controlled delay and allowed the airport to cover its costs. However, if the same fee were charged to air carrier, commuter, and GA aircraft, peak-hour pricing might be strongly resisted. Proportionately different fees for different categories of users might therefore be necessary.

Quotas

An alternative method for managing demand is to set a quota on the number of operations which can take place during a peak hour. The quota can be placed on total operations, or a certain number of operations can be allocated to different classes of users. The quota levels are usually set between the IFR and VFR capacity of the airport; thus, in VFR conditions, additional aircraft could easily be accommodated. When capacity is reduced, users without reservations have to use the airport at another time or use another airport.

Although reservations (slots) for GA or even air taxis might be allocated on a first-come, first-served basis, slots for scheduled carriers present a more complex problem. At major airports where quotas have been in effect for some time (O'Hare, JFK, La Guardia, and Washington National) representatives of the air carriers are allowed (with antitrust immunity) to meet as scheduling committees to negotiate how many slots will be allocated to each carrier. Although new entrants are able to participate in these negotiations, quota systems do tend to favor the status quo. Since the air traffic controllers strike in August, 22 airports have been brought under a quota system designed principally to ease peaks of demand on the en route ATC system. The methods for assigning slots to new entrants or allowing existing carriers to exchange slots are still under development.

One objection to quota systems is that the allocations are made without any price signals to show that the capacity is being used efficiently. Thus, although the quota may provide some stop-gap congestion relief, it does not provide any long-run guide for allocating resources as the system grows or changes. It has been suggested that this problem could be overcome by auctioning the reservation slots among the carriers or by combining the quota system with some sort of peak-hour pricing scheme.

Balanced Use of Metropolitan Area Airports

Many major metropolitan areas are served by two or more large airports. Where one or more of these airports is underutilized, possibilities exist for increasing airside capacity through a more balanced use of the region's airports. Examples include: Newark Airport, which is underutilized compared to Kennedy and La Guardia; Oakland Airport, which could relieve San Francisco; Midway Airport, which is practically empty while Chicago-O'Hare has delay problems; and Baltimore-Washington and Dulles Airports, which might relieve Washington National. The problem of balancing use of metropolitan airports presents a chicken/egg dilemma: airlines won't serve the underutilized airport because there are so few passengers, and passengers don't go there because there is so little service. It is difficult to foresee when congestion in itself will become great enough to cause redistribution, or to what extent the process can or should be managed by local or even Federal authorities. In some cases, better transportation between airports might make it easier to transfer between flights and to attract passengers to underutilized airports.

The Washington, D.C., area is illustrative of the problems of imbalanced airport use. Washington National Airport, operating since the mid-1940's, is convenient to the downtown area. National has three runways (all under 7,000 ft) and does not accept wide-body jets. Both its airside and landside capacity are severely limited and a quota system and airline scheduling committee are used to ration peak-hour operations. Expansion is difficult due to surrounding development and the Potomac River. Complaints about the airport's noise have led to a 10 p.m. curfew among other noise abatement policies. From time to time some groups even call for the airport to be closed.

Many of these problems could be alleviated if some operations were transferred to Dulles International Airport, 26 miles from Washington. Dulles, opened in 1962, has two 11,500-ft runways, one 10,000-ft runway and capacity to spare. FAA (which operates both airports) has repeatedly attempted to induce carriers to use Dulles more; for example, only Dulles can receive international and long-range domestic flights. Despite the constraints of the quota system, the curfew, and the restrictions on wide-body and long-range flights, however, National handled nearly 4 times the operations and 4½ times the passengers that Dulles did in 1980. Further, National generated a net profit of $10 million that year, while Dulles incurred a net loss of $3 million.[5] The principal problem is ground access; it is more convenient to fly from National than from Dulles.

Some new airlines beginning service since deregulation have sometimes deliberately chosen to operate out of underutilized airports to avoid congestion and delay. One example is Midway Airlines, which uses the nearly abandoned Midway Airport for its Chicago service. Midway's problem is also related to ground access: congested highways make trips to the airport long even though Midway is closer to downtown Chicago than O'Hare. Another example is People Express, which serves the New York area from Newark. The Port Authority of New York and New Jersey has been offering incentives to passengers as well as airlines to increase the use of Newark Airport: improved ground access by train and express bus allows New York City passengers to get to Newark without paying high interstate taxi fares, and new airlines are offered more and better space for future growth at Newark. In addition to People Express, New York Air has located part of its operation at Newark. Now that permission has been gained to use Newark as a international airport, several established airlines are also bidding to offer transatlantic service from there.

Restructuring Airline Service Patterns

When delay becomes intolerable at busy hub airports, users themselves may voluntarily move their operations to another facility. This movement might be to an underutilized airport nearby (e.g., Newark), but it could also be to a medium or small hub located at some distance from the congested hub. This is especially likely for transfer traffic. (See ch. 4 for a discussion of the growth and capacity impacts of this redistribution scenario.)

Many major airports currently serve as hubs for a large amount of transfer traffic. Three-fourths of the arriving passengers at Atlanta and about one-half the passengers at O'Hare Dallas-Fort Worth and Denver pass through these airports only to change planes for somewhere else. Carriers choose to establish their hubs at these busy airports so that passengers can choose from many transfer flights. However, when the transfer airport becomes too congested the disadvantages of delay may begin to outweigh the advantages of convenience, for airlines as well as passengers. Hence carriers may decide to locate their new transfer operations, and even move their existing hubbing activities, to other cities that have more room for growth.

Redistribution of operations appears to be occurring under the new routing freedom available under the Airline Deregulation Act of 1978. Carriers are finding it easier to change their routes and establish new "second-tier" hubs at less congested airports. Between 1978 and 1980 the number of large hubs (handling more than 1 percent of total U.S. passenger traffic) fell from 26 to 24, while the number of medium hubs (handling 0.25 to 0.99 percent) increased from 33 to 36—a market shift reflecting the distribution of operations over more airports. This trend may accelerate as regional carriers modify their patterns of service, and even the busiest airports such as Atlanta and O'Hare, may see actual declines in both enplaned passengers and operations in the next 10 years. A similar decline in operations occurred at Kennedy Airport when international flights were allowed to enter the United States at other gateway cities.

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[5] Interviews, FAA, Metropolitan Washington Airports, July 6, 1981.

Reliever Airports

In metropolitan areas where there is congestion at the main airport and excess capacity at surrounding airports, diversion of GA traffic would be effective in improving the use of airside capacity in the whole region. It would allow a higher level of service for both air carrier and general aviation, and in most metropolitan areas there are smaller airports which might potentially attract some GA traffic away from the main airport. For example, FAA lists 27 airports in the Chicago area, 51 around Los Angeles, and 52 in the Dallas-Fort Worth metropolitan area. However, most of these airports are quite small, and only a few have runways long enough to accommodate business jets or instrument landing equipment for bad-weather operations.

The FAA's National Airport Systems Plan (NASP) designates 155 airports as "satellites" or "relievers" to major airports, and NASP provides for separate Airport Development Aid Program (ADAP) funding to be set aside for relievers. Publicly owned reliever airports may use ADAP funds for construction, installation of safety equipment, and other eligible expenditures. The 25 or so privately owned reliever airports, although they presumably provide the same benefit in terms of diverting traffic from congested air carrier airports, are not eligible for aid. Local and State governments may, however, use ADAP funds to help purchase privately owned reliever airports, and at least five reliever airports have changed from private to public ownership since 1973. One privately owned reliever, Chicagoland (a reliever for O'Hare) closed in 1978. Although the FAA reliever program was initiated largely to segregate training activities from major commercial airports in the interests of safety, it also provides additional airport capacity for a certain type of traffic—namely, personal GA aircraft with origins or destinations in the local region; business and commercial GA (i.e., corporate aircraft and air taxis) delivering or picking up airline passengers will probably continue to use the major commercial airport.

The process of diverting the personal GA traffic has already occurred at the Nation's largest major commercial airports. The fraction of GA activity at Atlanta, O'Hare, Kennedy, Los Angeles International, etc., is very small (about 10 percent) because these regions have good alternate secondary airports with high levels of traffic. In fact, some of the large relievers such as Van Nuys and Long Beach, Calif., Opa Locka, Fla., and Teterboro, N.Y., are among the busiest airports in the country in terms of annual operations. This trend toward establishing a system of reliever airports is underway and has been endorsed by many user groups and observers, most recently the President's Task Force on Aircraft Crew Complement.[6]

To be of maximum benefit the reliever airport should be located so that approach and airspace conflicts between the reliever and the commercial airport do not place capacity limits on both. In the New York area, for example, instrument operations at Linden and Teterboro reliever airports must alternate with operations at the Newark Airport. In addition, the noise consequences of increasing operations at the reliever airport must be considered. Most reliever airports have, or will soon have, IFR landing aids and runway systems capable of handling sophisticated GA aircraft. To be most attractive to users, airports should also have commercial services for aircraft servicing, repair and maintenance, ground transportation, and flight crew amenities. With sufficient amenities, such an airport might even attract some commuter airline service, although transfers and interlining would be difficult unless the airport is served by several carriers or has excellent ground access to a major hub. In some cases, however, the provision of better facilities may not be sufficient to divert additional GA traffic away from major hub airports. Increased landing fees at the major airport can provide additional incentives for this shift, and such pricing policies—the domain of local government and airport authorities—could be looked upon as a complement to the Federal program of investment in satellite airports.

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[6] *Report of the President's Task Force on Aircraft Crew Complement* (Washington, D.C.: July 2, 1981).

AIRPORT DEVELOPMENT ALTERNATIVES

Expanding Existing Airports

Because runway availability is the major constraint on airside capacity, one way to increase capacity is to add more runways. A new long runway, properly equipped for independent IFR operations can increase an airport's capacity by 20 to 50 percent depending on the original runway configuration.

Adding another runway, however, requires a large amount of land. One 11,000-ft runway for large jet operations with its basic safety areas covers 130 acres, and when other necessary "clear zones" are considered, an area three to four times that size would be directly affected. Further, the additional operations enabled by the new runway would probably require landside additions such as new gates, terminal space, and parking for more passengers. Few airports have the necessary land for this kind of expansion, which could add approximately 10 percent to their present area, and for some airports like Washington National and La Guardia, the prospect is especially bleak. Even for larger airports, obtaining proper spacing from other runways would be extremely difficult.

A 1977 report by the Department of Transportation (DOT) studied the possibility of major expansion at 24 airports to meet projected needs for 1985-2000. Expansion was found to be "feasible" in only four of these cases, and none of these four airports (Detroit, Houston, Minneapolis, and Pittsburgh) are among those which are experiencing the greatest capacity problems. In 9 other cities the DOT study found expansion "feasible within major constraints," and in 11 cases it was considered "not feasible." Both economic and environmental reasons were cited for preventing the land acquisition.[7] Airport designers foresaw the need for growth and most major airports were built where land was plentiful, but sites that were on the edge of town in 1925 or 1948 are now in the middle of urban development. In some cases the airport itself attracted businesses; in other cases development simply resulted from good highways, suburbanization, and all the other forces which have caused urban areas to expand over the years. Developed land tends to be expensive to buy: a recent study of the cost to acquire and clear land around some major air carrier airports estimated these costs at between $100,000 and $200,000 per acre.[8] Noise is among the largest environmental obstacles to airport expansion. Chicago-O'Hare has sufficient land for an additional runway, but the runway has not been built in part because it would cause unacceptable noise exposure in nearby neighborhoods. JFK Airport in New York is surrounded by intensive development on one side and a National Park and Wildlife Sanctuary on the other, making expansion unlikely. Dallas-Fort Worth, on the other hand, is planning an additional major new runway that is expected to ease some of the capacity limitations imposed by noise abatement procedures and airspace conflicts with nearby Love Field.

Development of Secondary Runway Operations

At some airports where major expansion is unlikely it may still be possible to add one short runway for smaller, slow-moving commuter and GA aircraft. This could improve airport capacity by diverting traffic from the longer runways and may also provide a partial solution to the wake vortex problem (previously discussed). Many airports routinely use short runways, or sections of long runways, for small aircraft during good weather, but because of inadequate landing aids or spacing these runways cannot be used during bad weather; all-weather operations would require additional navigational and approach guidance equipment.

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[7] *Establishment of New Major Public Airports in the United States* (Washington, D.C.: Federal Aviation Administration, August 1977), p. 6-5.

[8] Louis H. Mayo, Jr., "Noise Compatible Land Uses in Airport Environments," *Environmental Comment*, March 1979, p. 9.

One study found that the use of short IFR runways for small aircraft was feasible at 11 of 30 major airports. Of these 11, suitable runways already existed at 3 airports, existing runways could be extended for use at 2 others, and at 6 airports space was available for short runways to be constructed. The study estimated that the value of reduced delays brought about by the addition of such runways might be $450 million to $810 million in current dollars between 1980 and 1990 at the airports shown in table 10. The benefits would be unevenly distributed: Chicago, Atlanta, Philadelphia, and Denver would receive 80 to 85 percent of the estimated savings; among the users, 86 to 89 percent of the savings from reduced delays would accrue to the air carriers.[9]

A detailed study of the airfield and airspace at each airport would be needed to see if the short runway could really be constructed. Such studies done at Denver revealed two possible locations for a short GA runway. Construction of either one could lead to a 35 to 70 percent increase in hourly operations, depending on weather conditions. Total cost was estimated at about $10.8 million.[10]

Building New Airports

Another way to increase airport capacity is to build a completely new airport to replace or supplement the existing one, an alternative that is especially attractive where landside facilities (terminals, baggage equipment, parking) are also outmoded or inadequate. A new site would provide the opportunity to design and build runways, terminals, and parking space to meet future needs, rather than making do with what has evolved over time. Sufficient land could be purchased to allow for future growth and proper land-use controls could be applied so that noise compatibility problems do not arise again. In some recent airport relocations, however, this did not work as well as hoped. For example, at both Dallas-Fort Worth Regional Airport and Kansas City International Airport, built in the mid-1970's, encroachment by other land uses is again leading to complaints about airport noise. On the other hand, Montreal's new Mirabel Airport seems to have little problem with noise incompatibility; the airport itself covers 17,000 acres, and is surrounded by an additional 21,000 acres controlled by a specially created municipal authority. However, its distance from the city makes access a problem.

Building a new airport also provides an opportunity to add a large amount of new airside capacity to a region. The opening of Kansas City International, for example, more than doubled the available capacity in that hub from the estimated 195,000 operations at the old municipal airport to about 445,000 with the new airport. Love Field in Dallas handled 410,000 operations in 1972; in 1977, after air carrier operations were transferred to Dallas-Fort Worth Regional Airport, Love Field still had 310,000 operations (mostly GA), while the new airport had 385,000.

A 1977 investigation by DOT found that anywhere from 2 to 19 new airports might be needed in the United States by the year 2000, depending on the growth rate assumed.[11] When the study examined the feasibility of new airport construction for 10 hub areas, it found it to be "feasible" in four instances, "doubtful" in four, and "not feasible" in two. The reasons for the "doubtful" and "not feasible" findings are related primarily to site location, land acquisition, funding problems, and the difficulty of providing adequate ground access to a remote location. The FAA's 1980 NASP foresees the possibility of a new airport opening at Palmdale, Calif. (near Los Angeles), within the next 10 years; some initial work on new airports at Atlanta and San Diego might also be expected within the next decade.[12]

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[9] John D. Gardner, *Feasibility of a Separate Short Runway for Commuter and General Aviation Traffic at Denver*, prepared for the Federal Aviation Administration by The Mitre Corporation, McLean, Va., May 1980, pp. 1-1.

[10] John D. Gardner, *Extensions to the Feasibility Study of a Separate Short Runway for Commuter and General Aviation Traffic at Denver*, prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., September 1980, pp. 4-3 and 7-1.

[11] *Establishment of New Major Public Airports*, op. cit., p. 7-16.

[12] *National Airport System Plan Revised Statistics 1980-1989* (Washington, D.C., Federal Aviation Administration, 1980) p. vi.

Table 10.—Operational Characteristics of Airports With Potential Benefits From a Separate General Aviation Runway

Modification	Parallel independent operations	Parallel dependent operations	Nonparallel dependent operations
New runway	Chicago[c], Atlanta[c], Dallas-Ft. Worth[c], Denver	Philadelphia, Pittsburgh[a,b]	
Existing runway or taxiway		Detroit[a,b]	Portland, St. Louis
Extension of Existing runway		New York (JFK)[a], Indianapolis	

[a] The general aviation runway is independent of 1 of 2 air carrier runways for departures.

[b] General aviation runway handles departures only

[c] Triple parallel runways.

SOURCE: J. D. Gardner, "Feasibility of a Separate Short Runway For Commuter and General Aviation Traffic at Denver," prepared for the Federal Aviation Administration by Mitre Corp., McLean, Va., May 1980.

Building a new airport is a huge undertaking. A new air carrier airport can represent an investment of $5 billion, to be shared among the airport sponsor (and local taxpayers), airport concessionaires, the airlines (through their landing fees), and the Federal Government. Even a modest-sized GA airport would cost several hundred million dollars. The length of time required for planning and construction of a large airport—up to 10 years—can also add substantially to costs. Political and institutional factors can also pose substantial difficulties. Building an airport requires agreement from existing air carriers to move to the new facilities, but while a new airport can reduce delays it will also increase airline costs, and they must be convinced that the benefits will outweigh the costs. Further, approval and support of a number of State, county, and municipal governments, not to mention highway districts, zoning commissions, and various citizens' interest groups, must also be secured.

In some cases the divergent interests of different governments and constituencies can snarl the process. In St. Louis, for example, a site for a new airport was selected across the Mississippi River in Illinois. The Illinois State government was a major supporter of the project, as were the St. Louis city government and FAA. The opponents included citizens groups of the county where the new airport would be located (who objected on environmental grounds), the State of Missouri (which did not want the airport moved out of the State), and groups in St. Louis (which did not want the city to give up the close-in Lambert Airport). The project was debated for several years, but it was shelved after a change in the St. Louis city government.

Photo credit: Federal Aviation Administration

The design of a modern airport: Dallas-Fort Worth

ATC IMPROVEMENT ALTERNATIVES

As mentioned earlier, existing ATC procedures and equipment can represent constraints on the airside capacity. Improvements in these areas can increase the number of aircraft operations.

Airfield/Airspace Configuration Management

The ATC team at an airport decides how the runway and ATC equipment should be used based on wind, visibility, traffic mix, ratio of arrivals to departures, noise-abatement procedures, and the status of the airport (which run ways or landing aids are under repair, etc.). In a large air carrier airport like O'Hare, there may be 40 or 50 ways in which the runways can be used, so deciding which one offers maximum capacity for any particular set of conditions is a complex task. The problem is compounded by the interdependence of runway use and the configuration of the surrounding airspace. For example, changing which runway is used for landings may change the route that approaching aircraft must take through the terminal airspace, which may in turn affect or be affected by activity at other airports in the vicinity.

One FAA analysis of capacity and delay problems in Chicago suggested that proper management of airfield and airspace could have a large payoff:

> Optimized management of the air traffic control system . . . could achieve now, at minimum investment cost, savings comparable to those that will be achieved much later at much higher cost when third generation ATC hardware is deployed. This highlights the importance of FAA management exploration of opportunities for improved system efficiency by placing emphasis on optimization of operations at least equal to that given development of ATC hardware.[13]

After study of the runway system of O'Hare airport, the task force found that a computerized airspace/airfield management system could be used to assist the controller team in selecting the highest capacity and most energy-efficient runway use for each set of circumstances.

Such a system could have several levels of complexity. In its basic form it would aid in selecting the preferred runway configuration for a given set of conditions; this basic system is under development by FAA. The intermediate form would update this assessment as changes in weather or traffic conditions arise, and then select the most efficient means of making the transition from the one configuration to another. (This is important because the transition period is often a time when airspace and airport capcity are wasted.) The advanced version would have the ability to make longer term strategic decisions. The 1978 Chicago task force suggested that savings of $11 million to $16 million annually in reduced delay costs might be expected from the basic system alone.[14]

Wake Vortex Prediction

Alleviation of the wake vortex problem offers the possibility of a substantial potential payoff in increased capacity without large capital expenditures for new runways. Research over the past decade has shown some possible ways of doing this. For example, it has been found that certain wind conditions can quickly dissipate a vortex or remove it from the path of oncoming traffic. If wind conditions can be accurately monitored and quickly analyzed, then the likelihood of wake vortex danger can be known on a minute-by-minute basis.

FAA has been testing such a system at O'Hare Airport since 1977. Wind sensors are located on 50-ft towers near the runway ends. A computer analyzes wind conditions and when persistent vortexes are unlikely it gives the controller team a "green light" to permit reduced separations on final approach. To have maximum effect (e.g., to allow all separations to be reduced to 3 nmi), an advisory system would have to be able to predict the likelihood of wake vortexes at greater distances and higher altitudes than the Chicago system now does. However even this prototype system has been credited with allowing reduced average separations, and thus more operations per hour, at O'Hare. There are no current FAA plans for implementing full scale wake vortex advisory systems at other airports.

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[13] *Delay Task Force Study, Volume I: Executive Summary, O'Hare International Airport* (Chicago: Federal Aviation Administration Great Lakes Region: July, 1976), p. 4.

[14] Ibid.

Microwave Landing System (MLS)

As discussed in chapter 5, MLS allows airspace to be used more efficiently than the current ILS, since aircraft would be able to approach the airport on curved paths, as they do under visual conditions, and turn onto their final approach much closer to the runway.[15] Variable MLS glide slope angles could also provide a partial solution to the long separations required to avoid wake vortex; with MLS, the trailing aircraft could avoid the vortex by approaching the runway at a steeper angle than the lead aircraft.

Models suggest that where the traffic mix contains a variety of fast and slow aircraft, the use of variable glide slopes could allow some capacity improvements—perhaps around 10 to 15 percent. However, where aircraft have similar performance characteristics, MLS landing procedures would offer about the same capacity as current ILS procedures. MLS would also allow the restructuring of airspace at some airports, so that small aircraft can approach the airport in a separate arrival stream from jets and make use of a separate short runway. The Dash-7 aircraft in Ransome Airlines' Washington-Philadelphia service use MLS equipment to land on short runways.

MLS equipment has been developed, tested, and accepted for international use. Field evaluation is taking place at such airports as Washington National, and FAA has published a plan for full-scale implementation beginning in the mid-1980's and to continuing into the next century. One reason for this delayed schedule may be the international agreement to maintain ILS until 1995; and another reason is the reluctance of users, principally the airlines, to install MLS avionics in aircraft already equipped with ILS avionics.

Reducing Separation or Spacing Minimums

Several studies have suggested that where wake vortex is not a problem (for example, where aircraft have similar performance characteristics) it may be possible to reduce separations from 3 nmi to as little as 2.5 or 2 nmi. The amount of time each aircraft spends on the runway is another constraint in reducing separations, and depends on such factors as the number and spacing of the exits, visibility, runway surface conditions, and the performance characteristics of the aircraft. In general, small, light aircraft spend less time on the runway than large, heavy ones. According to surveys, most airports have an average runway occupancy time of between 41 and 63 seconds for landing,[16] although these figures do not include the rare snowy or icy days when separations might have to be extended to allow time for aircraft to brake safely and exit the runway. Where the average runway occupancy time is 50 seconds or less, it has been suggested that the minimum separation could safely be reduced to 2.5 nmi instead of 3 nmi. Greater reductions might be possible through automated metering and spacing.

Another way of increasing airfield capacity is to reduce the required spacing between runways. For example, runways must be 4,300 ft apart for simultaneous IFR operations to take place. Reduction of this minimum to 3,500 or 3,000 ft would enable some airports to make use of more of their runways during IFR conditions. Minimum spacing standards have been reduced before (e.g., from 5,000 to 4,300 ft for independent parallel IFR runways in the early 1960's) as a result of improvements in surveillance equipment and procedures.

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[15] *An Analysis of the Requirements For and the Benefits and Costs of the National Microwave Landing System, Volume I* (Washington, D.C.: Federal Aviation Administration, June 1980), p. 2-3.

[16] William J. Swedish, *Evaluation of the Potential for Reduced Longitudinal Spacing on Final Approach*, prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., p. 4-1.

FAA is also investigating the possibility of allowing instrument approaches to triple parallel runways during poor visibility. Currently triple parallels can be used only during good visibility. One of these three runways might be a short runway for commuter or GA aircraft. Efficient use of triple parallels would require redesign of the airspace and approach patterns, a higher degree of coordination between approach controllers than is currently the case, and possible modifications to the ILS. MLS, with its greater flexibility and navigational precision, might be useful in bringing this procedure into practical use. Use of triple parallels could make it possible to make use of more existing runways during poor weather, as at O'Hare, or even to allow construction of new runways which are infeasible under current procedures. Capacity improvements would depend on traffic mix and on whether the runways had sufficient spacing to allow independent operations. Models indicate that triple parallel runway systems might handle up to 50 percent more IFR operations than double parallels with traffic mixes typical of today's major airports.[17]

A number of airports have been identified which might benefit from either reduced spacing standards or from use of triple parallel approaches.[18] However, site-specific analyses of the airfield and airspace of each candidate airport are needed to measure the capacity benefits, costs, and safety effects of these proposed changes.

Automated Metering and Spacing

The controller's ability to meter aircraft—to deliver them to a specific point at a specific time—is based on aircraft speed and position as shown on the radar screen and the controller's instructions to change speed or direction in order to arrive at the runway threshold at the proper time. Using this manual system the controller's training and experience allow him to deliver aircraft to the runway threshold with an error (standard deviation) of about 18 seconds.[19]

It has been suggested that an automated system could provide more accurate metering and spacing. In such a system, the ATC computer could analyze radar and transponder data directly and compute future aircraft location with great accuracy, then generate commands designed to deliver each aircraft at a specific time and thereby optimize the use of the runway's capacity. It has been suggested that an automated system could reduce the delivery error to about 11 seconds.[20] The automated concept has been under development at FAA for about 10 years but has not yet been approved for implementation. FAA states that the computerized methods developed so far are not as reliable as a human controller. In addition, FAA believes automated terminal metering and spacing will not be of much value unless it can be tied in with en route metering and other aspects of ATC automation now under development (see ch. 5).

Cockpit Engineering

Advances in technology are in fact changing the basic character of the cockpit. Electromechanical instruments are being replaced with electronic displays that present full-color images with a very high degree of resolution. Computers are also expanding the range of functions that can be performed by aircrew. Advanced navigation aids such as area naviation (RNAV) make it possible to navigate from point to point without following established airways. The FAA has suggested the use of a data link to improve the quality of the information available in the cockpit. A cockpit display of traffic information (CDTI), currently under investigation at the National Aeronautics and Space Administration could show pilots the locations of nearby aircraft, thus reducing their dependence on ground surveillance. Both RNAV and CDTI offer pilots significant independence from controllers, and this could increase the effectiveness with which airport and airway facilities are used. There have been suggestions that the distribution of the decisionmaking function in the ATC system must or should be changed to take advantage of the capabilities these technological advances have made possible (see ch. 5).

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[17] T. N. Shimi, W. J. Swedish, and L. C. Newman, *Requirements for Instrument Approaches to Triple Parallel Runways*, prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., 1981, p. E-7.

[18] L. C. Newman, T. N. Shimi, and W. J. Swedish, *Survey of 101 U.S. Airports for New Multiple Approach Concepts*, prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., 1981, p. xxiv, 5-4, 6-2; and A. L. Haines and W. J. Swedish, *Requirements for Independent and Dependent Parallel Instrument Approaches at Reduced Runway Spacing*, prepared for the Federal Aviation Administration by The Mitre Corp., McLean, Va., 1981, passim.

[19] *New Engineering and Development Initiatives—Policy and Technology Choices*, coordinated by Economic and Science Planning, Inc. (Washington, D.C.: Federal Aviation Administration, March 1979) p. 107.

[20] *Parameters of Future ATC Systems Relating to Airport Capacity/Delay* (Washington, D.C.: Federal Aviation Administration, June 1978).

SUMMARY OF ALTERNATIVES

The alternatives discussed above all make use of some combination of economic, regulatory, or technological tools to reduce delay or increase airside capacity. For example, peak-hour pricing is an economic alternative—allowing the market to allocate scarce airport capacity. Quotas, on the other hand, rely on the application and enforcement of regulatory measures to deal with the delay problem. Automated metering and spacing is a technological tool, but its use will require changes in existing rules and standards. Table 11 summarizes the alternatives discussed

Table 11.—Summary of Alternatives

Alternative	Economic incentives	Regulation	Technology	Comments
Demand-related				
Peak hour pricing	•			Could be implemented by local airport authority. Devising and managing the pricing scheme may be complex, but it could provide a substantial long-term payoff in reduced delay.
Quotas		•		Could be implemented by local authority or FAA. Would provide some short-term relief for congestion and delay problems but is an inefficient long-term solution. FAA has already imposed quotas at 4 airports since 1969.
Balanced use of metropolitan airports	•	•		Could be implemented by local authority which might use economic incentives, improved access, and better facilities to encourage use of underutilized airports; or could use regulation to impose it.
Change of airline service patterns	•	•		Airlines may voluntarily shift some of their hubbing activities to less congested airports to save delay. (This trend seems to already be underway.) The FAA might also be able to achieve this redistribution by regulation. This would make better use of airport capacity nationwide, but might do little to reduce delays at congested airports.
Reliever airports	•	•		FAA has already designated reliever airports. Many are well used by GA traffic. Local authorities encourage this trend with pricing strategies, better facilities, or regulations requiring use of relievers by certain classes of users. Relievers have been and will continue to be successful in providing capacity for GA operations away from congested commercial airports.
Airport development				
Airport expansion	•			Responsibility of local authorities, possibly with Federal aid. Could greatly increase capacity, but is unlikely in many locations because of surrounding development or environmental problems.

Table 11.—Summary of Alternatives (Continued)

Alternative	Economic incentives	Regulation	Technology	Comments
Addition of short runway	•			Possible in several airports to provide a separate traffic stream for GA and commuter aircraft. Increases capacity for both small and large aircraft. Responsibility of local authority with possible Federal aid. Cost estimate for Denver was $10 million to $11 million.
New airport construction		•		Responsibility of local authorities with Federal assistance. Could have a major impact on local airside capacity, but is unlikely in many areas due to expense, lack of close in suitable land. Good high-speed ground access might make more distant airports likely in long range.
ATC alternatives				
Airfield/space management		•	•	Allows modest capacity gains by making better use of the runways available. Computerized system has been tested in Chicago. Similar system could be developed and implemented in other areas by local authorities and FAA.
Wake vortex prediction		•	•	FAA would be responsible for installing vortex detection or advisory equipment. FAA has tested one wake vortex advisory system which provides some capacity benefits, but is still in the experimental stage.
Microwave landing system		•	•	Benefits are more efficient use of airspace and availability of variable glide slopes which, among other things, can allow aircraft to avoid wake vortexes. Fairly substantial increases in capacity available where traffic mix is diverse. The technology now exists and FAA will probably install ground equipment in the 1985-2000 period. FAA's installation costs are estimated to be $300,000 to $500,000 per airport. Users costs for avionics will range from $1,500 to $30,000 per aircraft.
Reduced separation or spacing standards		•	•	Responsibility of FAA. Reduction of these standards could offer large capacity increases, but FAA's first priority is safety of the system. Reduction of standards is unlikely without some technological change—elimination of wake vortex problem or improved navigation or surveillance.
Automated metering and spacing		•	•	Increased accuracy of metering could optimize runway use, offering modest capacity increases. FAA has not yet developed a program which it feels ready to implement. FAA wants to integrate terminal automated metering and spacing with the automated en route system, implementation might not be possible until after the replacement of the en route computer system.
Cockpit engineering		•	•	RNAV technology is already available. Users must buy the avionics, FAA is responsible for developing RNAV procedures which might reduce delays somewhat. Cockpit displays of traffic information are being developed and tested by the FAA but will not be available in the near future.

SOURCE: Office of Technology Assessment.

above and indicates generally what types of tools—economic, regulatory, or technological—would be required to implement them. The comments in table 11 touch on several points—who can implement the change, whether it would make a large or small change in capacity, and how likely it is to take place in the short or long term.

In general, the *demand-related alternatives* do not increase capacity; rather, they reduce delay by molding traffic activity to fit existing capacity. Modest capacity gains are available through *ATC improvements* that increase the efficiency with which airfield and airspace are used, especially under IFR conditions, but the benefit available to each airport is heavily dependent on local conditions of runway configuration and traffic mix. The addition of *new runways* is clearly effective in increasing capacity, but this option is available to only a limited number of airports. In a few cases, *short runways* could be constructed to increase capacity by separating jet and propellor traffic. *New airport* construction also offers large capacity gains, but they would likely be further from cities and therefore face the problem of ground access. *Reliever or satellite airports* to move GA out of air carrier airports are necessary unless the growth of both user groups is to be severely limited, but reliever airports will also be constrained by land prices, noise impacts, and community acceptance.

FUTURE RESEARCH NEEDS

Several areas offer possibly fertile ground for future research on means to increase airport airside capacity.

Wake Vortex Avoidance

The FAA's wake vortex advisory system has been discussed, but more research is needed to develop operational versions of this system which can predict vortex problems at greater distances from the runway ends—say, back to the ILS middle marker or outer marker. FAA has also studied the use of acoustical radar and lasers to detect actual vortexes. Although some progress has been make in understanding the nature of vortexes, these techniques are far from operational. However, with further research this line of inquiry may be the basis for a ground-based or airborne wake vortex detection system.

Wake Vortex Alleviation

Also important is the possibility of modifying or minimizing vortexes at the source. NASA research has shown that certain combinations of flaps, spoilers, or protrusions on the wings of aircraft can cause the wake vortex to be unstable and therefore to dissipate more quickly. Trailing aircraft can then follow closer in safety. These methods, however, also tend to increase the noise level and decrease the energy efficiency of the aircraft. More work needs to be done to develop a system which minimizes the vortex with an acceptable price in terms of noise and fuel.

Noise

Many current noise abatement procedures require a tradeoff in terms of reduced airspace and airport capacity. As long as aircraft remain noisy, however, there is little alternative to routing them away from noise-sensitive areas. Some new and re-engined jet aircraft are much less noisy than their predecessors, but it has been suggested that technology may have gone as far as it can, and that administrative solutions are the only alternative. In any case, a great deal of further research is needed to develop creative solutions to the noise problem.

Airport Design

The scarcity of suitable land for expanding existing airports or building new ones means that new research is needed on basic concepts of how an airport and its access system should be designed. For example, it may be possible to redesign the runway-taxiway system in a manner that is less profligate of land. Research is needed into the safety and capacity questions raised by this type of design. In some locations where little land is available for a new airport, it may be possible to locate an airport on a nearby lake or bay. Such an airport would be expensive to build, even when the necessary technology has been developed, but in some cases it might be the most cost-effective alternative.

Ground Access

Airport access is a major area of concern. Research is needed not only to alleviate the access problems plaguing some of today's major airports, but also on cost-effective means to get passengers out to new airports which may have to be constructed at distances of 30 to 50 miles from the city center.

Chapter 7

POLICY IMPLICATIONS

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Chapter 7

POLICY IMPLICATIONS

INTRODUCTION

The letter from the House Committee on Appropriations requesting this assessment indicated the following areas of concern:

- scenarios of future air transportation growth;
- alternative ways to increase airport and terminal capacity;
- proposed modifications of air traffic control (ATC) system technology; and
- alternatives to the present ATC process.

OTA's analysis of these subjects is presented in chapters 4, 5, and 6; this chapter summarizes the major points emerging from those analyses and examines their implications in terms of congressional interests. The intent is to highlight those aspects of air system evolution that may be of particular concern to the Congress in evaluating the Federal Aviation Administration's (FAA) 1982 National Airspace System (NAS) Plan .

The following discussion is organized under three major headings. Under each heading is a brief statement of findings followed by a discussion of specific problems and implications. A fourth section deals briefly with the related questions of funding and cost allocation, which must also be addressed in the years ahead. The final section reviews recent congressional reports on these subjects and identifies the relevant legislation now pending before Congress.

AIR SYSTEM GROWTH

Findings

Chapter 4 compares recent FAA *Aviation Forecasts* and those of several other sources. The following major points emerge from that comparison:

- FAA projections of future demand have consistently been too high in the past, in part because of the way they are made: they assume that past trends will continue, that there will be no constraints on continued rapid growth, and that proposed ATC improvements will in fact be made when and where needed to accommodate that growth. However, other sources (including Rolls Royce and the Air Transport Association) feel that the airline industry is already approaching its mature size; this could lead to a leveling off or even a decline in air carrier operations There is also considerable uncertainty about a number of other factors that might affect future aviation activity, such as changes in U.S. economic or regulatory policy, the long-term impacts of airline deregulation and the PATCO strike, and the ability of airlines to finance new equipment. Given these uncertainties and the questionable economic assumptions underlying the 1981 baseline projection on which the 1982 NAS Plan will be based, Congress may wish to reexamine the deployment schedule proposed by FAA for major ATC system improvements.
- There will be some growth in the system, but the rate of growth will be slower than was experienced in the past and may be slower than has been anticipated even in recent forecasts. The various scenarios suggest that a 2- or 3-percent annual growth rate for total operations at FAA-towered airports would be a reasonable expectation, although the rate might be as low as −1 percent or as high as +5 percent, depending on a variety of economic, regulatory, and operational factors that cannot be reliably predicted. En route and flight service workloads are likely to increase as fast or faster than tower operations.

- There is disagreement about the exact distribution of this future growth among user groups, but the forecasts generally agree that general aviation (GA), and especially air taxis and corporate aircraft equipped for IFR operations, will be the fastest growing category. GA may account for as much as 75 percent of the increase in tower workload, particularly if FAA (as planned) increases the number of towered GA and reliever airports. Commuter operations will increase moderately, on the other hand, and air carrier *operations* (not passenger traffic) may actually decline at some hubs.
- The relatively rapid growth of GA demand, combined with the slower growth of commuter and air carrier operations, could have several effects on the U.S. airport and ATC system:
    —Unconstrained growth of operations at major hubs would lead to saturation at 15 to 20 airports by 2000, compared with 5 to 10 airports today. Growth rates above 4 percent annually, which are possible but unlikely, might result in saturation at
    —all 50 of the top air carrier airports by the end of the century.
    —In the absence of capacity improvements at saturated hubs, increasing congestion and delay will probably result in further redistribution of air carrier operations (especially transfer functions) away from saturated major hubs to "second tier" hubs where surplus capacity still exists.
    —Similarly, GA traffic is likely to be shifted out of more and more air carrier hubs to reliever and other GA airports. This will create a demand for improved facilities at those airports.
    —As a result, the principal opportunities for capacity expansion will come not at the major hub airports but rather at the second-tier hubs and at GA and reliever airports, as well as at the air route traffic control centers and flight service stations. If these increases in ATC system capacity are to be provided without greatly increasing FAA's operation and maintenance (O&M) expenditures, expanded use of automated and remote facilities will be required.

Discussion

Forecasts of aviation activity are subject to three principal kinds of uncertainties, all of which affect the accuracy and usefulness of the resulting projections of airport and ATC system demands:

- There is no common purpose or focus—airline forecasts concentrate primarily on measures of carrier profitability, aerospace forecasts on potential aircraft markets, and FAA forecasts on ATC workloads.
- All of the projections nevertheless employ a similar methodology and rely on similar demographic and economic expectations. Specifically, the forecasts assume a continuation of the past relationship between gross national product growth and increased demand for air travel. As a result, common-mode failure is possible—the forecasts could all be wrong for the same reason.
- All of the forecasts are subject to factors whose future influence can only be guessed at, including the price and availability of fuel, the effects of airline deregulation, the resulting changes in industry structure, the long-term impacts of the air controllers strike, the uncertain availability of financing for reequipping airline fleets, and future changes in Federal aviation policy or cost allocation.

As a result, there is general agreement on the likelihood of future growth, but little certainty about its magnitude, and still less about the more important questions of when and where growth will occur or what its impact will be on the Nation's airport and ATC system.

Continued growth along historic patterns would exacerbate congestion and delay at hubs that are already saturated and would probably spread these problems to additional airports. This would present two possible courses of response:

- accommodate the growth wherever it occurs (as FAA has done in the past) by at-

tempting to expand the capacity of affected hubs; or
- channel the growth, either actively or passively, so that it can be accommodated at other hubs.

Neither of these courses will be applicable in all situations, and in most cases the solution will involve some combination of the two: finding the proper balance will require a case-by-case analysis of their relative costs and benefits.

Adding new capacity at congested hubs—in the form of new runways or entirely new airports—could be extremely expensive in relation to the number of additional operations that can be accommodated. There are, however, a number of traffic management techniques that could increase the efficiency with which existing capacity is utilized at airports and terminal areas that are already saturated.

There are clear indications that market forces have already begun to alter the historical patterns of demand distribution. Some airlines, faced with high delay costs and strike-related restrictions at congested hubs, are finding it attractive to move some of their "hubbing" or transfer operations to well-equipped second-tier hubs where available capacity exists and delay costs can be avoided. Local service airlines, with the new route and entry freedom of deregulation, are beginning to increase the number of direct-service flights, and, consequently, to decrease the number of transfer operations. New entrants and low-cost carriers, unencumbered by large investments in facilities at congested hubs, are basing their operations at second-tier hubs. Although this trend may involve a small decrease in the operational efficiency of system users, it would greatly increase the efficiency with which the airport and ATC system's aggregate capacity is utilized.

Growing congestion could have serious implications for commuter and GA users, who would be at a considerable disadvantage in any competition for access to congested hubs. Neither user group is likely to be completely priced or regulated out of major hubs, but growing congestion may nevertheless prove to be a significant constraint on their future growth. Additional GA operations might be accommodated at reliever and other GA airports; this would make more capacity available at existing hubs, but it could also lead to additional FAA investments and operating costs for new towers at lightly used GA airports. (FAA plans have called for as many as 50 new towers by 1993, but its experience in closing over 60 low-volume towers since the PATCO walkout justifies a review of these plans.) Commuter carriers, on the other hand, will continue to require access to hub airports, since most of their passengers transfer to other flights. Rehubbing by major airlines will not change this requirement and might even create additional complications in commuter routes and operations, although it might also create new market opportunities for commuter airlines. In addition, commuter and GA users will generate most of the new demand for en route and flight services.

AIRPORT CAPACITY ALTERNATIVES

Findings

The committee asked OTA to examine the "relative merits of alternative ways of increasing airport and terminal capacity to meet future demands and reduce safety hazards." The tools that can be used to increase capacity or reduce delay are examined in chapter 6, where the major findings and implications are:

- Changes in ATC equipment or procedures can produce small increases in airside capacity by helping aircraft use available airspace and runways more efficiently. However, large capacity improvements, such as would result from greatly reducing the distance between aircraft on landing and takeoff, must await technological breakthroughs like improved prediction of wake vortices.
- Where ATC improvements are made, they

would not necessarily eliminate the problem of delay: latent demand at a popular airport could quickly consume new capacity, and the length of delay would remain the same.

- Major increases in the physical capacity of a hub would require building new runways or entire new airports. Such major improvements are unlikely to be made in the near future because of the unavailability or high price of land, costs of construction, and noise and other environmental constraints.
- If growth continues, however, some new major airports may have to be built. Since they are likely to be some distance from the center city, the success of these airports will depend upon suitable high-speed ground access. (Dulles International Airport demonstrates the need for such access.)
- Congestion at large hub airports may induce use of a variety of techniques to maximize effective capacity, including hourly quotas and peak-hour pricing. GA users are likely to be the major losers in competition for slots at congested airports, although these restrictions might also constrain the growth of commuter carrier operations.
- If air carriers continue to redistribute their transfer operations to second-tier hubs, some added investment will be required at these airports.
- In the near term, two forms of capacity expansion can be helpful: 1) construction at congested airports of separate, short runways, equipped for instrument operations, for use by small aircraft; and 2) construction or improvement of reliever airports to accommodate GA traffic diverted from congested commercial airports.

Discussion

Some improvements can be expected from changes in ATC equipment or procedures in congested terminal areas; but the net effect on delay would be quite small. For instance, computerized airfield/airspace management might allow better utilization of *existing* physical capacity, so that actual operations would approach the theoretical maximum for each combination of weather and traffic conditions. The Microwave Landing System (MLS) might also allow a small increase in the number of Instrument Flight Rules (IFR) operations under certain conditions of traffic mix. In general, mostly because of the separation required by the danger of wake vortex, there will be no significant ATC-related increase in the number of aircraft operations that can be handled by a given runway, airport, or terminal area.

Past Federal, State, and local airport policy has been to provide new capacity where demand seemed to warrant it, if at all possible. Most of today's congested airports have gone through periods of major expansion, only to become saturated by subsequent growth. As urban transportation planners have discovered, *additional capacity is not always the solution to the problem of delay.* Building a new lane does not appreciably ease traffic jams on a busy freeway, for instance, because new traffic is attracted by the improved link and delays quickly reach the previous level. The same principle applies to many hub airports: the busier an airport is, the more demand there is for access to it, simply because it *is* busy and thus offers a wide choice of connections and services. Adding new capacity may merely tap this latent demand—the airport can accommodate those it couldn't handle before, but the new traffic quickly saturates the additional capacity and delay soon rises to previous levels. This doesn't mean that expansion is futile, but it should be evaluated in terms of its benefits and the available alternatives.

If expansion proves impractical, the 15 to 20 airports that will become saturated by the end of the century will probably have to make wider use of demand-managing alternatives—peak-hour pricing, quotas, or access restrictions—to deal with the problems of congestion and delay. These tools do not increase peak capacity; they shift traffic to a time or place where it can be better handled, thus increasing effective capacity. Pricing schemes to ration scarce landing slots place the greatest burden on operators of small aircraft, since they have a smaller base of passengers over which to spread cost. Administrative quotas may also tend to favor larger aircraft, which serve more passengers and generate higher landing fees. In either case, commuters and GA users will have the greatest difficulty in competing for slots at crowded airports. Not all GA activity could be displaced, since some GA flights must use the main airport to deliver passengers connecting with commercial flights. Even at the busiest airports GA operations currently tend to average about 10 percent of total operations.

The separation of fast and slow (or jet and prop) traffic is one ATC procedure that could benefit both types of traffic. Most GA and commuter aircraft can use shorter runways than those required for large jet liners, and at some busy commercial airports the construction of short runways equipped for instrument operations could allow continued accommodation of commuter and GA aircraft, and at the same time, could also allow some secondary increase in jet aircraft operations. These separate, short runways would be especially important for commuter carriers whose business depends on being able to land at major airports, and in many cases they would add more capacity relative to cost than a new mixed-traffic runway.

Another means of separating traffic that will become increasingly important is the diversion of some GA traffic from commercial airports to reliever airports. This technique has some drawbacks. For example, users may resist going to a "second best" airport which may not offer the same services or ground access as the commercial airport. On the other hand, a properly equipped GA reliever can often provide better service to nonscheduled private traffic than the main airport could. Constructing, improving, or upgrading these airports would be largely the responsibility of local authorities, but Federal assistance (in the form of the Airport Development Aid Program (ADAP) or other grants) is currently available for the 155 reliever airports included in the NAS Plan. The level of funding for relievers in the recent past has been a little under 25 percent of all grants for GA airports, or 4 to 6 percent of all airport grants.

ATC SYSTEM IMPROVEMENTS

Findings

Future improvements in the ATC system will be directed toward three general objectives:

- replacing obsolete equipment with improved technology that is more effective and reliable and less costly to operate and maintain;
- expanding system capacity to accommodate expected growth; and
- adding new capabilities to increase the productivity of the system and the efficiency of its users.

Two improvements are basic to this process: 1) achieving higher levels of automation on the ground, and 2) taking advantage of the capabilities of flight-management avionics that are appearing in the user fleets. In the 1980's, the major effort will be devoted to replacing the computers in the en route centers, modernizing the flight service stations, and beginning the deployment of the MLS, the Discrete Address Beacon System (DABS, now Mode S), and the Traffic Alert and Collision Avoidance System (TCAS). For the 1990's, the FAA's plans included further implementation of the Mode S data link and MLS and the start of a long-range program of automation in en route and terminal area ATC centers. The FAA plans are undergoing a major review, however, and there are indications that the FAA's 1982 NAS Plan will include changes in both technology and timing.

In general, OTA finds that the ATC system improvements previously proposed by FAA in the areas studied are technologically feasible. In four of the five major areas addressed by OTA, however, detailed cost and benefit information is not yet available. This information will be needed on all major programs before final judgment can be made on FAA proposals. The specific findings and potential issues in the five program areas studied by OTA are set forth under separate headings below.

Computer Replacement

The computers used in en route ATC centers will need to be replaced within the next 10 years because the present IBM 9020 computers do not have the computing speed or storage capacity needed to accommodate the expected growth in air traffic at the most heavily used en route centers. These computers also lack the capacity to support more automated modes of operation that FAA estimates will be needed to assure future system safety or to increase ATC system productivity. There is also concern that the cost of repairing and maintaining the present computers will become excessive, largely because the IBM 360 series computers used in the 9020 are no longer in production and replacement parts would ultimately have to be specially made.

An important issue in the computer replacement program is the procurement strategy to be followed. The program previously recommended by FAA was a total replacement strategy which would require about 10 years to complete and would entail specially designed ATC hardware and software to meet near-term needs and serve as the foundation for more advanced automation in the 1990's and beyond. The schedule called for the first operational contract to be let in 1988, with installation of production systems starting in the 1990's. The costs of this program were at one time estimated at nearly $1.7 billion (1980 dollars), over the 1982 to 1991 period.

Alternatives to this total replacement strategy include incremental approaches which could provide relief to computer capacity problems in a shorter time—perhaps 3 to 4 years as compared to 10 years for total replacement. For example, a "software first" approach would focus on rewriting ATC software to reflect modern modular programing techniques. Then software for particular ATC functions could be gradually transferred to new computers which would at first supplement and finally replace the 9020s. A "hardware first" strategy would involve transferring (rehosting) the existing software package to a new computer. Later this software could be modified along more modern lines or totally replaced to support new functions and services.

There are technical difficulties to be overcome in each of these incremental strategies, but they have the advantages of allowing the replacement process to begin quickly. The use of off-the-shelf hardware would appear to offer some cost savings over specially designed equipment. Further it would ensure that compatible hardware is available to upgrade or expand the system at a future date.

Automated En Route Air Traffic Control (AERA)

Part of the rationale for en route computer replacement is to satisfy the long-term evolutionary requirements that are now defined in a general way under the concept of AERA. The essence of this concept is to transfer from controllers to computers some routine activities, such as separating and metering aircraft or formulating and delivering clearances. Relieved of these routine tasks, the controller's role would be primarily to handle exceptions and emergencies and to oversee (manage) the operation of automated ATC equipment. Automation could achieve several benefits: increasing controller productivity and reducing FAA personnel costs; reducing user costs by permitting wider use of fuel-efficient flight profiles; accommodating more operations; and reducing system errors.

The AERA concept requires a great amount of ground-based data processing to perform extensive and detailed management of aircraft flight paths. It could also reduce many of the procedural constraints now imposed on the use of airspace. In effect, it would be a system of management by exception: intervention by a controller would be limited to circumstances or localities where conflicts could not be reliably resolved by computer algorithms.

The major advantage claimed for AERA, aside from more comprehensive management of traffic, would be a substantial increase in controller productivity. It is contemplated that AERA control sectors would be staffed by one or perhaps two (rather than the present three) controllers and that the volume of airspace controlled would be several times the size of present en route sectors. A substantially greater number of aircraft could thus be handled by a controller team. On the other hand, this load would almost certainly be heavier than human operators could handle in the event of computer failure. As a result, the AERA concept includes provisions for automated backup for automated functions, as well as a computer design that will allow the system to "coast" safely while backup procedures are being initiated.

It must be emphasized that at present AERA is only in an early stage of development. Extensive efforts over perhaps 5 to 10 years will be needed to bring AERA to a precise and detailed definition of requirements and equipment specifications.

Three major features of AERA are already apparent. First, AERA would require computer capacity and software substantially beyond that now available in ATC applications, although not beyond the present or readily foreseeable state of technology. Second, AERA will require a two-way data link capable of rapid and extensive exchange of information between the air and the ground. FAA now envisions that Mode S will provide this data link, but other possibilities could be considered. Third, AERA implies a like degree of automation in the terminal areas and in a central flow management facility capable of coordinating traffic throughout the ATC system. This last point is particularly important for both short-term computer replacement and long-term system design, since it implies the advisability of procuring a computer having a modular architecture. This would make it possible for en route and terminal facilities to utilize similar hardware and software; it would also encourage a flexible system design, in which individual modules would be capable of mutual support and backup in the event of partial equipment failure.

Close scrutiny by Congress will be needed as FAA's plans mature. One major issue is likely to be the acceptability to the users and controllers of an ATC system automated to the degree envisioned in the AERA concept, especially its safety and operational reliability. A second major issue will be evaluation of the savings in operation and maintenance ascribed to AERA, compared to the needed investments in facilities and equipment to implement the system. A corollary issue will be the costs and benefits to various classes of airspace users. The information to support judgments ~~on~~ these matters is not now available, and OTA can reach no conclusion beyond the general observation that resolving these issues is likely to be far more important than seeking answers to the rather narrow question of technical feasibility.

Mode S Data Link

Another key element in the FAA's overall plan for improving the ATC system is the Mode S data link, an improvement to the secondary surveillance radar that allows properly equipped aircraft to be interrogated selectively by ground stations. Mode S provides greater surveillance accuracy than the present Air Traffic Control Radar Beacon System (ATCRBS) equipment and avoids the problem of "synchronous garble" that occurs when more than one aircraft respond simultaneously to interrogation. The discrete address capability also provides a two-way ground-to-air data link to transmit clearances, weather information, traffic advisories, control instructions, and flight data automatically in a digital format without using VHF voice channels. The Mode S data link feature provides the basis for automation of ATC functions and other system improvements in the years beyond 1990.

Mode S has been under development by FAA for nearly 10 years at an estimated cost to date of $58 million. The first prototype unit was delivered for test and evaluation in 1978, and a contract for initial production will be awarded in 1982. FAA has not yet issued a formal implementation plan, but the preliminary plan calls for a multiyear procurement and deployment starting in 1986, at 197 sites—97 in terminal areas and 36 in the en route system, plus 60 for low-altitude coverage and 4 at support facilities.

Deployment at these 197 sites would not constitute full implementation of Mode S. Additional installations, which would not be completed until early in the next century, might be needed at another 100 sites to provide coverage down to 6,000 ft for the continental United States and perhaps portions of Hawaii and Alaska.

An issue that will need to be addressed during examination of the plans for Mode S has to do with the extent to which a Mode S transponder would be required before permitting an aircraft to enter airspace or receive services (e.g. access to and operation in a terminal control area [TCA]). Mode S and ATCRBS Mode C are compatible, so that in the short run either system would qualify users to operate in TCA. GA operators, however, have expressed concern that the Mode S format would eventually supplant ATCRBS Modes A and C and that they would be required to reequip their aircraft with Mode S transponders. This concern would be reduced by assurances that ATCRBS could be utilized for an extended period following the initial implementation of Mode S.

Collision Avoidance

The primary function of air traffic control is to assure the safe separation of aircraft. In the present system, this is accomplished by controllers on the ground using surveillance radar and computer aids; when conflict is detected, the controllers use voice radio to advise pilots of traffic or instruct them to perform appropriate avoidance maneuvers. At present, the pilot has no instrument or display in the cockpit to identify potential threats or to indicate a maneuver that would resolve a conflict.

For many years, FAA (in cooperation with the aviation community) has investigated a number of collision avoidance systems that would provide a backup (rather than a substitute) for the current ATC procedures and ground-based separation assurance service. During the summer of 1981, FAA selected a system known as TCAS. FAA plans for TCAS to be operational by the end of 1984, a goal that is considered by some to be optimistic. FAA has justified the choice of TCAS on the following grounds:

- it does not require ground-based equipment;
- it is compatible with the present ATC system and is a logical extension of it;
- it offers a range of capabilities suitable to the needs of the various classes of airspace users; and
- it is more suitable for use in high-density traffic than the Beacon Collision Avoidance System (BCAS), the system that was favored by the FAA prior to the TCAS decision.

TCAS provides the user with protection from other aircraft regardless of whether they are equipped with TCAS or the standard ATCRBS transponder. In the active mode, TCAS interrogates other aircraft to determine whether they are threats. TCAS also identifies potential threats from ATCRBS-equipped aircraft by monitoring their replies to interrogations from the ground. A central feature of TCAS is the use of the Mode S transponder for the communication of data between aircraft. TCAS I, the system intended for use by general aviation, provides general Mode S capability and would cost $2,500 to $3,500 per aircraft. TCAS II, the version intended for use by commercial aircraft, would cost between $40,000 and $50,000 per set, plus the cost of antennas and installation. Some believe these estimates to be low. TCAS requires essentially no expenditures by FAA, except for development and certification costs; but since it will require Mode S for identification and data link, aircraft equipped with TCAS will be prepared to take advantage of any new services requiring data link that may be offered by FAA.

Although FAA has decided that it will certify TCAS as the collision avoidance system to be used in the United States, not all features of the system have been developed and demonstrated. The TCAS II direction-finding antenna is of critical importance: there is some question regarding the aerodynamic effects of the antenna on aircraft performance, particularly the performance of tactical military aircraft. TCAS I, on the other hand, has been demonstrated; but it is not clear how useful this more basic form will be since it only indicates the proximity of another aircraft without providing either bearing or range.

Prior to selecting TCAS, FAA was pursuing development of active BCAS. Because there was concern that omnidirectional BCAS might interfere with the surveillance system in congested areas by saturating ATCRBS transponders, FAA was also planning to base conflict resolution in areas of high traffic density on DABS/Automatic Traffic Advisory and Resolution Service (ATARS), a ground-based system that would require expenditures of $518 million to equip terminal and en route facilities. The decision to adopt TCAS has led FAA to reevaluate the need for DABS/ATARS.

Microwave Landing System

Another important component in the FAA's development plans is MLS, a precision landing aid designed as a replacement for the Instrument Landing System (ILS) that has been in use since the early 1940's. MLS is less sensitive to interference and distortions than ILS and will work at sites where it is difficult or impossible to install ILS. It is also anticipated that MLS equipment will be more reliable than ILS. The chief operational advantage of MLS is that it permits variable glide slopes, curved and segmented approaches, and precision missed approaches, where ILS does not. This would allow traffic to be routed around noise-sensitive areas and would also allow greater flexibility in handling traffic in crowded TCAs. MLS can operate on 200 channels (compared to 20 for ILS) making it possible to provide precision landing aid in areas where closely spaced airports limit the availability of ILS channels.

FAA has announced plans to implement MLS in three phases over the coming 11 to 16 years, with 1,200 to 1,400 systems eventually installed. In the first phase, between 10 and 25 systems will be installed at selected airports in order to develop a base of experience and reach an empirical determination of the benefits that can be realized. The second phase would be the installation of 900 MLS units at the rate of 100 to 150 per year for a period of 6 to 9 years, with priority given to large and medium hub airports and those where ILS siting problems exist. The third phase would consist of installing of an additional 300 to 500 systems to meet the growth in demand anticipated during the remainder of this century. FAA estimates the cost of 1,425 MLS ground systems to be $1.332 billion (1981 dollars), and users will be required to spend an additional $895 million for avionics if they wish to take advantage of this service.

OTA finds that the FAA's analysis of MLS benefits and costs does not establish a clear and universal case for MLS as opposed to ILS, and that for this reason the FAA plan for a first phase to gain the operational experience before the full deployment of MLS is entirely reasonable. However, at the end of the initial phase, it would be appropriate to conduct a comprehensive review of the MLS program before proceeding with further implementation. A part of this review should be development of additional increments or intermediate steps between the 25 sites planned for Phase I and the 900 planned for Phase II. Another part of this review should be more specific benefit-cost analyses that differentiate and specify the benefits at various airports in terms of levels of traffic, the types of users served, and the resulting reductions in noise, delay, or fuel consumption.

FUNDING AND COST ALLOCATION ISSUES

Findings

The program of airport development and ATC system improvement through 1991 previously proposed by FAA would require an expenditure of $1.6 billion to $1.9 billion per year, or about 50 to 75 percent above the spending level of recent years in real terms. Implicit in these figures is a commitment to spend roughly equal sums annually from 1992 to 2000 in order to complete programs already initiated and to undertake further improvements of the airport and airways system. These figures may change, however, as a result of changes in the forthcoming NAS Plan.

Historically, such expenditures have been financed from the Airport and Airways Trust Fund, which lapsed in October 1980 but had an uncommitted balance of about $3 billion at the end of fiscal year 1981. This sum would cover less than 20 percent of the 1982-91 programs contemplated by FAA.

Congress has two basic options to provide funding for the developing airports and airways over the coming years. One would be to cover these expenditures wholly by appropriations from general funds. The other involves funding through user charges by reestablishment of the trust fund in some form, including:

- Reestablishment of the trust fund with a revenue and user charges similar to those which existed prior to October 1980. *This would not cover the 1982-91 program of capital spending if—as in the past—some trust fund revenues were also spent for O&M.*
- Reestablishment of the trust fund, retaining the present forms of funding but increasing user charges to make revenues match projected expenditures. Rates could be raised either uniformly (across the board) or selectively (to alter the mix of contributions from various user classes).
- Reestablishment of the trust fund, but with a different form of user charges. Existing excise taxes might be replaced with user levies that would reflect more accurately the magnitude of the benefits received by various classes of users, or by a system that would charge individual users in relation to the costs they impose on the airport and airways system.

All of these options would be controversial and would exacerbate many long-standing issues pertaining to access to the system, user cost allocation, and subsidies to aviation. The search for a solution is further complicated by the fact that the cost of operating the airport and airways system would also be rising at the same time.

The disagreements over funding airport and airways improvements are so wide, and the sums so large, that the debate could conceivably extend over a number of years. To the degree that such a stalemate delays the funding of the FAA's proposed programs, some of the following courses of action might have to be considered:

- keep the existing equipment running as well as possible, with administrative restrictions on traffic levels as needed to keep demand within capacity;
- cut back on the proposed plans, dispensing with some improvements and funding only those for which there is the greatest or most immediate need;
- stretch out the procurement process over a longer period of time, in order to hold expenditures within the available revenues; or
- consider alternative technologies or funding mechanisms that shift more of the cost of the system to airspace users.

Discussion

Capital expenditures for airport capacity improvements and new ATC technology planned for the coming decade would result in a sharp increase in the FAA budget compared to the funding levels of the past 10 years. The combined expenditures for airport grants-in-aid, for ATC facilities and equipment (F&E), and for associated research, engineering, and development (RE&D) were in the range of $0.95 billion to $1.35 billion per year (in constant 1980 dollars) between 1971 and 1980 (see fig. 29).* Capital expenditures for fiscal year 1982 to fiscal year 1991 could total between $16 billion and $19 billion (1980 dollars), with $4.5 billion to $6 billion allocated to airport grants in aid, $10 billion to $11 billion for F&E, and $1.5 billion to $2 billion for RE&D. The combined outlay in these categories would amount to $1.6 billion to $1.9 billion per year, a real increase of 50 to 75 percent over the 1971-80 average.

A large part of airport expenditures throughout the 1982-91 period would be allocated to capacity increases at congested hub airports and development of GA reliever airports to take some of the pressure off large and medium hubs.

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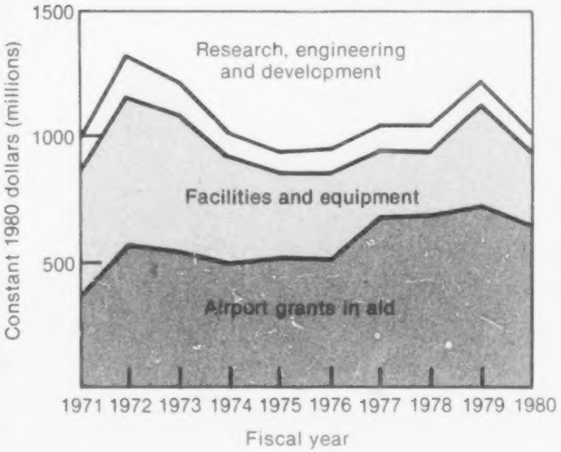
*In fiscal year 1980, the total in these three categories was $950 million; in fiscal year 1981, $885 million.

Figure 29.—Airport and Airways Trust Fund Expenditure 1971-80*



*Appropriations in various years for operating and maintenance expenses, totaling $3,370 million, are not shown. They amount to about 30 percent of all trust fund expenditures.

SOURCE: *FAA Monthly Management Report*, March 1981.

In the near term, the bulk of the F&E expenditures would be for replacement of en route computers, the first stages of MLS and Mode S implementation, and modernization of flight service stations. Beyond 1990, the major F&E expenditures would be for completion of en route automation, initiation of terminal area automation, and further deployment of MLS. Programs such as MLS, Mode S, and terminal and en route automation would not be completed by 1991; there would be a follow-on requirement for an additional funding in the 1990's to carry these programs to completion and to initiate further ATC technology improvements.

The FAA's justification for these planned expenditures is that they will be needed to relieve airport congestion, to enable the ATC system to handle higher traffic levels without compromise of safety, and to improve the efficiency (productivity) of the ATC system. Increasing productivity is especially important in view of the projected increase in aircraft operations and the resulting rise in ATC costs that would occur over the next 10 years if automated en route, terminal, and flight service station equipment were not installed.

Since establishment of the Airport and Airways Development Program in 1970, expenditures for airport improvements and ATC facilities and equipment, including the associated RE&D, have been financed by the Airport and Airways Trust Fund. Between fiscal year 1971 and fiscal year 1980, the trust fund provided $4 billion in airport grants, $2.6 billion for F&E, and $0.7 billion for RE&D. During the same period, the trust fund also provided almost $2.2 billion for O&M expenses of the ATC system. Expenditures from the trust fund have never exceeded revenues, and as of the end of fiscal year 1981 the trust fund had an uncommitted balance of about $3 billion.

The principal source of revenue for the trust fund through fiscal year 1980 was an 8-percent tax on domestic airline tickets. Other taxes contributing to a lesser extent were a 5-percent waybill tax on air cargo, a 7 cents per gallon tax on jet fuel and gasoline used by GA, a $3 international departure tax, an aircraft use tax for propeller aircraft, and taxes on airplane tires and tubes. In fiscal year 1980, these taxes contributed $1.87 billion to the trust fund, with 85 percent coming from the domestic airline passenger ticket tax.

On October 1, 1980, the legislative authorization of ADAP and the trust fund expired and Congress declined to pass reauthorizing legislation. Since then, receipts from the passenger ticket tax (reduced to 5 percent) have been remitted to the general fund. The air cargo waybill, international departure, and aircraft use taxes have been abolished. Revenues from the tax on aviation gasoline (4 cents per gallon) and tube and tire taxes have been remitted to the Highway Trust Fund.

There are now several bills before Congress that would restore the trust fund. These proposals include provision for airline passenger ticket taxes between 4 and 6.5 percent, taxes on GA fuel, an air cargo waybill tax of 2 to 5 percent, and a $1 to $5 international departure tax.*

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*Generally, the Administration's proposal provides for higher tax rates than any of the House or Senate bills. The tax rate for GA jet fuel under the Administration's proposal would be 20 cents per gallon initially, rising to 65 cents per gallon by fiscal year 1986. The tax on aviation gasoline would rise from 12 cents per gallon in fiscal year 1982 to 36 cents per gallon in fiscal year 1986. In congressional proposals, the tax on fuel ranges from 4 cents to 8.5 cents per gallon.

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Many Members of Congress have voiced strong opposition to reestablishing the trust fund or increasing the present user taxes so long as there is a large uncommitted balance in the trust fund. Sponsors of the various bills have pointed out that reauthorization of trust fund taxes in some form will be necessary to provide revenue for projected airport and ATC capital improvements. They also point out that the trust fund is consistent with the position of the present Administration that, e.g., whenever the Federal Government provides a service directly to a particular industry, those who receive the benefit should bear the cost.

Regardless of the action taken on these proposals, the Administration and Congress will, in the long run, have to grapple with the question of how to finance planned airport and ATC capital expenses. The balance in the trust fund now would cover less than 20 percent of the outlays by FAA for 1982-91. If these funds were to be expended at the fiscal year 1981 rate of $1.6 billion annually and no new taxes were authorized, the trust fund would be exhausted by the end of 1983. Even if the most ambitious of the current tax proposals were to be enacted and if trust fund moneys were also used to defray about one-quarter of O&M expenses (as they were in fiscal year 1980), trust fund revenues would probably be insufficient to meet planned capital expenditure and O&M costs beyond 1987 or 1988.

Some of the implications of providing funding for FAA airport and airways programs by appropriations from the general fund or, alternatively, by reauthorization of the trust fund are discussed below.

General Fund

Capital expenditures for airports and airways could be financed from general revenues through annual appropriations. There are numerous precedents for this in other areas although it runs counter to the 10-year Federal policy of financing airport and airways improvements through a dedicated trust fund supported by user charges. Funding from general revenues has the basic advantage of giving the Congress close control of FAA capital programs through the annual appropriations process. On the other hand, financing from general revenues has several major disadvantages: it introduces additional uncertainty in to the funding process and might make it difficult to plan and implement long-range programs, which might be canceled or delayed during periods of budget austerity, perhaps to the detriment of the national airspace system. A corollary disadvantage is that the FAA's capital programs might have to compete with operational expenses for a share of the FAA budget and (if a choice had to be made) operational expenditures would probably receive first consideration since they cannot be deferred or curtailed as easily as capital expenditures.

Perhaps the greatest objection to general fund financing, however, has been that it would constitute a subsidy of aviation by the public, many of whom would receive no direct benefit: one-third of the adult population in the United States has never flown, and fewer than 10 percent use commercial or general aviation on a regular basis. Such an approach, it is argued, would also contradict the economic precept that the users of a special service should bear the cost of that service—a view that the present Administration has advocated strongly. It is argued by some, however, that the general public also benefits in many indirect ways from services provided to the aviation community, including mail service and air freight as well as use of the system by military aircraft.

Trust Fund

Financing airport and airways improvements from a trust fund, either like that which existed prior to October 1980 or in a modified form, is an approach favored by many observers. It provides a continuing and stable source of funds earmarked for capital programs, and it secures those funds directly from users of the system. On the other hand, it has the general disadvantage of any sort of trust fund: the statutory restrictions on the purposes for which moneys may be used might limit Congress' flexibility in meeting other, perhaps more pressing, needs. The long-standing controversy over use of Airport and Airways Trust Fund monies for meeting annual O&M expenses of FAA is a clear illustration of this.

If Congress elects to continue the trust fund approach, as most of the pending bills pertaining to funding FAA's capital programs now propose, there are several options open:

- *Reauthorize the Airport and Airways Trust Fund as it existed before October 1980.* This fund, supported by various user excise taxes, would provide for some or all of FAA's capital expenditures over the coming decade. Whether it could also meet some portion of operating expenses would depend on the rates established for the various user taxes. Much of the current debate in Congress is on this specific point: i.e., the appropriate amount of taxation to be imposed on each class of airspace user.
- *Retain the tax mechanisms of the former trust fund but substantially alter the scheme of taxation,* so that each category of users would pay a share more nearly proportionate to the benefits they received. In the trust fund as constituted before October 1980, commercial aviation (domestic and international air carriers and air cargo airlines) contributed 93 percent of the revenues but, according to cost allocation studies by DOT and FAA, received a smaller share of the benefits—in effect, cross-subsidizing GA. Since nearly all of the revenues from commercial aviation were derived from the tax on airline tickets, *the subsidy to GA was actually provided by airline passengers,* not airlines. The Administration's recent proposal would redress this imbalance somewhat by greatly increasing the tax on fuel for GA aircraft, but it would probably still fall short of levying charges on GA commensurate with the benefits received, especially by business aircraft operating in and out of hub airports.

  Private GA operators and the makers of GA aircraft have vigorously opposed such tax schemes, on the grounds that Visual Flight Rules (VFR) and IFR users impose greatly different costs on the ATC system, and that high fuel taxes would reduce aircraft utilization in the short run and reduce sales of GA aircraft in the long run. They also state that the ATC system was designed to meet the needs of air carriers, and a few hub airports, with facilities and services that GA users neither asked for, nor want, nor need. In this sense, some GA users claim that they subsidize commercial air traffic. A third, and perhaps more fundamental, objection raised by GA is that there is no accurate method of determining the value of the benefits received by GA or any other class of airspace user, and hence no sound basis for establishing an appropriate level of taxation.
- Levy charges on users, either based on the actual use they make of the airport and airways system or based on the burden they place on the system to provide various types of services. The United States may be the only major nation that does not routinely charge for the use of its airspace; many countries in Europe and elsewhere in the world levy charges for the use of terminal and en route airspace (based on distance, time, and type of service provided), in addition to landing fees like those collected in this country to defray the costs of airport construction, maintenance, and operation. The chief conceptual problem is how to quantify user benefits or determine the cost of a service. Two major attempts by FAA and the Department of Transportation (DOT) to develop such a methodology, the cost allocation studies of 1973 and 1978,[1] [2] met with major objections from various aviation groups on the grounds that costs could not be determined with sufficient accuracy and that an equitable formula for allocating costs had not been developed.

Assuming that the methodological problems could be overcome, there would still remain practical problems of how to assess user charges. The simplest and most direct method would be a charge for service at the time a flight plan is filed. While this would capture fees from IFR users, it might encourage some GA operators to fly "off the system" (i.e. VFR to smaller airports) in order to avoid airport and airway charges, perhaps to the detriment of safety. It would also create a bookkeeping and administrative task for FAA in levying charges for use of the system.

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[1] *Airport and Airway Cost Allocation Study: Determination, Allocation, and Recovery of System Costs* (Washington, D.C., U.S. Department of Transportation, September 1973).

[2] *Financing the Airport and Airway System: Cost Allocation and Recovery* FAA-AVP-78-14 (Washington, D.C.: Federal Aviation Administration, November 1978).

A second possibility would be to require all aircraft to have a transponder and to use surveillance data to compute charges based on the time in the system and the type of service received. While this would free users from financial transactions when they file flight plans, it would still impose on the ATC system a requirement for recording and billing user charges. In addition, the universal requirement for a transponder would be viewed by many owners of small GA aircraft as an extreme form of regimentation. A third possibility involves approximation of user costs through a combination of fixed and variable assessments on aircraft owners: fixed charges could be collected in the form of annual taxes based on aircraft occupants (including flight crew) according to aircraft characteristics or type of use.

Operating Costs

A corollary problem that Congress will have to deal with is how to meet the operating costs of the system. (Many of the planned capital improvements are intended to *reduce* these costs in the long term.) If these costs are covered primarily by appropriations from general revenues (the practice of many years), the taxpayers would be subsidizing special services for a mode of transportation that only a few use directly, although they may receive some indirect benefit. If paid wholly or largely by disbursements from the trust fund, as the Administration proposes and many Members of Congress oppose, the pressures on the trust fund would be greatly intensified. Over two-thirds of the FAA's annual budget goes to meet operating costs, but disbursements from the trust fund have covered only about 15 percent of these expenses in the past. To take a more substantial portion of operational expenses from the trust fund, as it is presently structured, would exhaust the current surplus in a very short time. To prevent this, and at the same time provide for needed capital investments, the taxes supporting the trust fund would have to be increased to yield significantly more revenue than contemplated by any of the legislative proposals before the Congress at this time. A tax increase of this magnitude would raise all of the issues cited earlier in connection with capital funding options and greatly exacerbate the conflict among the various stakeholders in the aviation community.

PENDING LEGISLATION

Areas of congressional interest in the airport and air traffic control system include system modernization (especially system automation and the replacement of the en route computers), airport development, trust fund usage, and user charges. This section briefly reviews congressional activities in the past 2 years, outlines the positions taken by various congressional committees on key issues, and identifies the major legislation now before Congress.

System Modernization

Major capital expenditures like the en route computer replacement have been the subject of several congressional hearings and investigations. A recurring question has been the FAA's ability to plan and manage such a complex procurement.

In October 1980, the investigations staff of the Senate Committee on Appropriations released a report criticizing the FAA's management of the existing ATC computer system. The report cited weaknesses in the reporting of equipment outages, a lack of planning, and the absence of a well-defined approach to managing system operations and software changes. The investigators recommended the Congress withhold funding for computer replacement until the FAA had demonstrated a better understanding of the capabilities and limitations of the existing system.

The report outlined specific actions FAA should take to improve its performance and evaluation methods.[3]

After two sets of hearings on the safety aspects of computer outages, the House Committee on Government Operations raised many of the same questions in October 1981. Their report found that the FAA's management information system did not provide accurate data on which to base important decisions about the reliability of the computer. The committee also questioned the FAA's ability to plan and manage the development and procurement of a new computer system. The report directed the General Accounting Office (GAO) to initiate a "comprehensive investigation of the FAA's planning, management, and acquisition of automated information systems."[4] The GAO final report, due in October 1982, will cover FAA planning and management for acquisitions in three areas: ATC system automation, management information systems, and peripheral equipment.

The Subcommittee on Transportation of the House Committee on Science and Technology, which has shown a continuing interest in the ATC computer question, has stated that the current computer system needs to be replaced and that unnecessary delay in doing so would pose safety risks and increase the chances of further breakdowns. In reviewing the alternatives for replacing the system, the subcommittee's report of August 1981 favored a full modernization of the computer system, as opposed to an interim replacement followed by a long-range procurement. The full committee recommended that FAA publish a management plan detailing the costs, schedules, milestones, and funding plans for the computer replacement.[5]

To give further emphasis to these findings and recommendations subcommittee chairman, Representative Dan Glickman introduced **H. Res. 202** in October 1981, which expressed the sense of the House that FAA should consult with the Committee on Science and Technology as it develops plans for the future ATC system. It also directed FAA to make regular reports to the committee, commencing with a system description in December 1981 and a preliminary subsystem description in June 1982. This resolution was passed by the House on October 19, 1981.

Airport Development Aid

The Federal role in airport development was previously governed by the Airport and Airways Development Act of 1970, which expired in October 1980 when the Congress could not agree to new authorizing legislation. Projects extending into fiscal year 1981 were funded, but no authorizations have been made for future years. In writing new authorizing legislation in 1981, the question of "defederalization" has been a major issue. Defederalization would remove large and medium hub airports from eligibility for ADAP funding, on the grounds that these airports generate enough revenues to be self-supporting without Federal aid.

The Senate version of the authorizing legislation, **S.508**, would make the top 69 air carrier airports ineligible for airport development and planning grants. The Administration position, as contained in **H.R. 2930** called for a more modest defederalization measure, making the top 42 airports ineligible for aid. These airports would be permitted to impose a limited passenger facility charge (head tax) to make up lost revenues (head taxes are currently forbidden at all airports that have received Federal aid). The report on **S.508** by the Senate Committee on Commerce, Science, and Transportation supports the defederalization concept and notes that ADAP funds make up a fairly small proportion of the total capital and operating budgets of larger airports. If they were made ineligible, the report points out, more Federal funds would be available for small airports unable to generate their own funds. Because the Senate bill limits the total authorization to $450 million annually for 5 years (1981-86), it is necessary to make those funds available to those who need them most.[6]

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[3] U.S. Congress, Senate Investigations Staff, *FAA's En Route Air Traffic Control Computer System*, submitted to the Subcommittee on Transportation and Related Agencies, Committee on Commerce, Science and Transportation, Rpt. No. 80-5, October 1980.

[4] U.S. Congress, House, Committee on Government Operations, *Air Traffic Control Computer Failures*, Rpt. No. 97-137, June 11, 1981.

[5] U.S. Congress, House, Committee on Science and Technology, Subcommittee on Transportation, Aviation and Materials, *Air Traffic Control En Route Computer Modernization*, Rpt. No. 97-12, August 1981.

The House version of the authorizing legislation, **H.R. 2643,** contains no provision for defederalization, and members of the Committee on Public Works who sponsored the House version have expressed opposition to the concept. Questions of equity are involved: opponents of defederalization are concerned that passengers using major airports would have to bear a double tax—the Federal ticket tax in addition to any local passenger facility charge. Further, the ticket tax on passengers at large airports already generates the bulk of revenues in the Airport and Airways Trust Fund, and it seems unfair to forbid these airports the use of those funds. The House bill proposes a $450 million annual authorization for 3 fiscal years.[7]

Trust Fund Usage

The uncommitted balance in the trust fund (about $3 billion at the end of fiscal year 1981) has long been a cause of controversy in Congress and among users. The Senate Committee on Commerce, Science, and Transportation attributes this balance to the fact that the OMB under previous administrations has sought to keep trust fund revenues high and expenditures low. The current administration has proposed drawing down the balance significantly by funding 85 to 100 percent of the FAA's operations and maintenance costs out of the trust fund, in addition to capital costs. For example, the administration budget recommended financing expenditures such as aviation security and aircraft inspection from the trust fund. Both Senate and House Committees on Appropriations, however, have continued to allow these regulatory and police functions to be funded from general funds.[8]

The Senate Committee on Commerce, Science, and Transportation stated that the airport and airway system provides benefit to the general public and therefore the general fund should continue to contribute to its operation.[9] Although many in Congress agree that something should be done to reduce the balance, some Members feel that taking operating costs out of the trust fund constitutes "raiding" the users' funds, which were collected for the purpose of improving the airways system, to subsidize activities that should be paid for out of general revenues. The DOT appropriations bill for fiscal year 1981, in both House and Senate versions, appropriated funds from the trust fund to cover about one-third of operating costs, about double the average share of the past 10 years. **H.R. 2643,** as reported by the Committee on Public Works, authorizes a ceiling of 50 percent on operating costs to be taken from the trust fund in future years; **S.508** authorizes a ceiling of about one-third on operating costs to be taken from the trust fund.

User Taxes

Current proposals for reestablishing the trust fund call for no major changes in the user tax structure. In general, the House, Senate, and administration positions on user charges have simply been differences in the level of tax in the traditional categories:

- The administration proposal, embodied in **S. 1047,** calls for the greatest increase in user taxes. It differentiates between GA gas taxes and GA jet fuel taxes, taxing gas at 12 cents per gallon (rising to 36 cents in fiscal year 1986) and jet fuel taxes at 20 cents (rising to 65 cents). The passenger ticket tax would be set at 6.5 percent, the waybill tax at 5 percent, and an international facilities charge of $3 per passenger would be authorized.
- Another bill, **S. 1272,** cosponsored by several members of the Senate Committee on Commerce, Science, and Transportation, calls for an 8.5 cent tax for all GA fuels, a 3 percent ticket tax, a 2 percent waybill tax, and a $1 international facilities charge.

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[6] U.S. Congress, Senate, Committee on Commerce, Science, and Transportation, Report to Accompany S.508, Airport and Airway System Development Act of 1981, S. Rpt. 97-97, May 15, 1981.

[7] U.S. Congress, House, Committee on Public Works and Transportation, Report to Accompany H.R. 2643, Airport and Airway Improvement Act of 1981, H. Rpt. 97-24 (Part II), May 19, 1981.

[8] U.S. Congress, House, Committee of Conference for the Department of Transportation and Related Agencies for the fiscal year ending Sept. 30, 1982, Conference Report to Accompany H.R. 4209, H. Rpt. 97-331, Nov. 13, 1981.

[9] Senate Commerce, Science and Transportation, S. Rpt. 97-97 op. cit.

- A House bill, **H.R. 4800**, calls for a 12.5 cents tax on all GA fuels, a 5 percent ticket tax and a $5 international facilities tax.

These measures are still under consideration by the Senate Committee on Finance and House Committee on Ways and Means, and it is uncertain how they will appear after committee markup. Part of the difficulty in reaching a decision on the tax level is the current uncommitted balance in the trust fund and the unwillingness of both past and present administrations to spend the money for its specified purposes. Members of the Senate Commerce Subcommittee on Aviation and the House Science and Technology Subcommittee on Transportation, Aviation, and Materials have stated they do not favor sharp increases in user charges until some use is made of the existing balance.[10]

The uncertainty about the costs and timing of future capital expenditures also clouds the discussion of tax levels. The options appear to be: 1) increase taxes to maintain a substantial balance in the trust fund in anticipation of large future expenditures, recognizing that the current balance could not cover the proposed program of system modernization; or 2) allow the trust fund to be depleted, knowing that revenues will have to be greatly increased later if these future expenditures are to be paid for by user taxes.

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[10] *Aviation Daily*, Nov. 19, 1981, p. 102.

Office of Technology Assessment

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